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MEASUREMENT AND CONTROL OF AIR POLLUTION PRODUCED BY HIGHWAY CONSTRUCTION

Rescan

FINAL REPORT

APRIL 1980

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Caltrans

CALIFORNIA DEPARTMENT OF TRANSPORTATION

TRANSPORTATION LABORATORY

FOUNDED IN 1912

RINGELMANN CHART AND EQUIVALENT OPACITY

Division 20, Chapter 2, Article 3, Section 24242 of the Health and Safety Code of the State of California states:

> "A person shall not discharge into the atmosphere from any single source of emission whatsoever any air contaminant for a period or periods aggregating more than three minutes in any one hour which is:
>
> (a) As dark or darker in shade as that designated as No. 2 on the Ringelmann Chart, as published by the United States Bureau of Mines, or
>
> (b) Of such opacity as to obscure an observer's view to a degree equal to or greater than does smoke described in subsection (a) of this section."

Ringelmann Chart

The Ringelmann Chart was one of the first tools used to measure emissions to the atmosphere (see attachment).

It was developed by Maximilian Ringelmann in the late 1800's and has been used by almost every industrial nation ever since. The Ringelmann Chart is thoroughly covered in the Bureau of Mines Information Circular No. IC 8333 (May 1967) and is partially reproduced below.

The Ringelmann Smoke Chart, giving shades of gray by which the density of columns of smoke rising from stacks may be compared, was developed by Professor Maximilian Ringelmann of Paris. Ringelmann, born in 1861, was professor of agricultural engineering at l'Institute

Agronomique and Director de la Station d'Essais de Machines in Paris in 1888, and held those positions for many years thereafter.

The chart apparently was introduced into the United States by William Kent in an article published in Engineering News of November 11, 1897, with a comment that he had learned of it in a private communication from a Bryan Donkin of London. It was said to have come into somewhat extensive use in Europe by that time. Kent proposed in 1899 that it be accepted as the standard measure of smoke density in the standard code for power plant testing that was being formulated by the American Society of Mechanical Engineers.

The Ringelmann Chart was used by the engineers of the Technologic Branch of the U. S. Geological Survey (which later formed the nucleus of the present Bureau of Mines) in their studies of smokeless combustion beginning at St. Louis in 1904, and by 1910, it had been recognized officially in the smoke ordinance for Boston passed by the Massachusetts Legislature.

The chart is now used as a device for determining whether emissions of smoke are within limits or standards of permissibility (statutes and ordinances) established and expressed with reference to the chart. It is widely used by law-enforcement or compliance officers in jurisdictions that have adopted standards based upon the chart.

In 1908, copies of the chart were prepared by the Technologic Branch of the Geological Survey for use by its fuel engineers and for public distribution. Upon its organization in 1910, the Bureau of Mines assumed this service together with the other fuel-testing activities of the Technologic Branch.

DESCRIPTION AND METHOD OF PREPARING THE CHART

The Ringelmann system is virtually a scheme whereby graduated shades of gray, varying by five equal steps between white and black, may be accurately reproduced by means of a rectangular grill of black lines of definite width and spacing on a white background. The rule given by Professor Ringelmann by which the charts may be reproduced is as follows:

Card 0 - All white.

Card 1 - Black lines 1 mm think, 10 mm apart, leaving white spaces 9 mm square.

Card 2 - Lines 2.3 mm thick, spaces 7.7 mm square.

Card 3 - Lines 3.7 mm thick, spaces 6.3 square.

Card 4 - Lines 5.5 mm thick, spaces 4.5 mm square.

Card 5 - All black.

The chart, as distributed by the Bureau of Mines, provides the shades of cards 1, 2, 3, and 4 on a single sheet, which are known as Ringelmann No. 1, 2, 3, and 4, respectively. Additional copies of the chart may be obtained free by applying to the Publications Distribution Branch, Bureau of Mines, 4800 Forbes Avenue, Pittsburgh, Pa. 15213.

USE OF CHART

Many municipal, state, and federal regulations prescribe some-density limits based on the Ringelmann Smoke Chart, as published by the Bureau of Mines. Although the chart was not originally designed for regulatory purposes, it is presently used for this purpose in many jurisdictions where the results obtained are accepted as legal evidence.

While the chart still serves a useful purpose, it should be remembered that the data obtained by its use is empirical in nature and has definite limitations. The apparent darkness or opacity of a stack plume depends upon the concentration of the particulate matter in the effluent, the size of the particulate, the depth of the smoke column being viewed, natural lighting conditions such as the direction of the sun relative to the observer, and the color of the particles. Since unburned carbon is a principal coloring material in a smoke column from a furnace using coal or oil, the relative shade is a function of the combustion efficiency.

While the Ringelmann Smoke Chart has many limitations, it gives good practical results in the hands of well-trained operators. However, it is questionable whether results should be expressed in fractional units because of variations in physical conditions and in the judgment of the observers.

To use the chart, it is supported on a level with the eye, at such a distance from the observer that the lines on the chart merge into shades of gray, and as nearly as possible in line with the stack. The observer glances from the smoke, as it issues from the stack, to the chart and notes the number of the chart most nearly corresponding with the shade of the smoke, then records this number with the time of observation. A clear stack is recorded as No. 0, and 100 percent black smoke as No. 5.

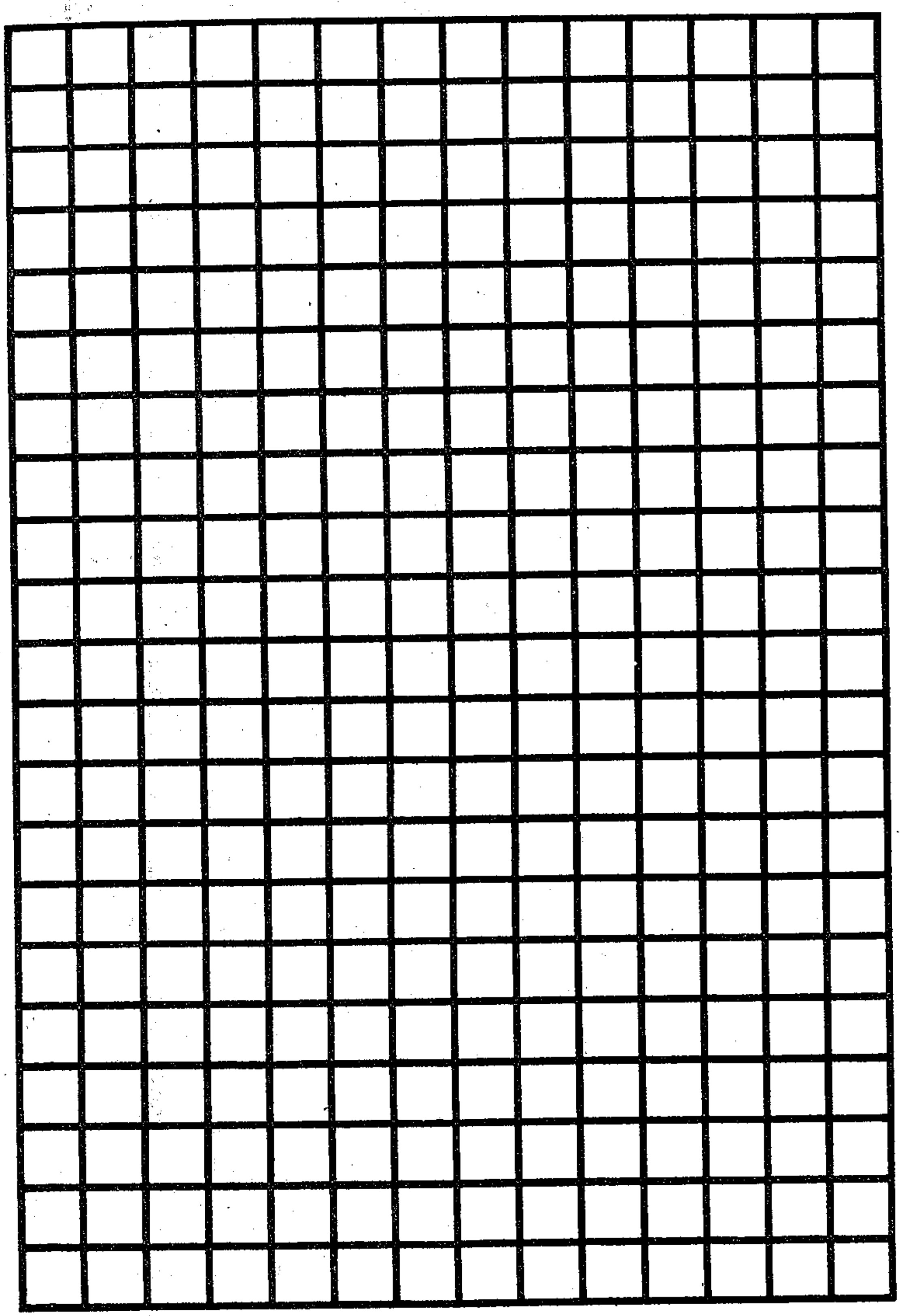
Equivalent Opacity

Although the Ringelmann Chart is only useful in evaluating black or gray emissions, a principle of equivalent opacity was developed later which makes possible the application of the Ringelmann principle to other colors of smoke.

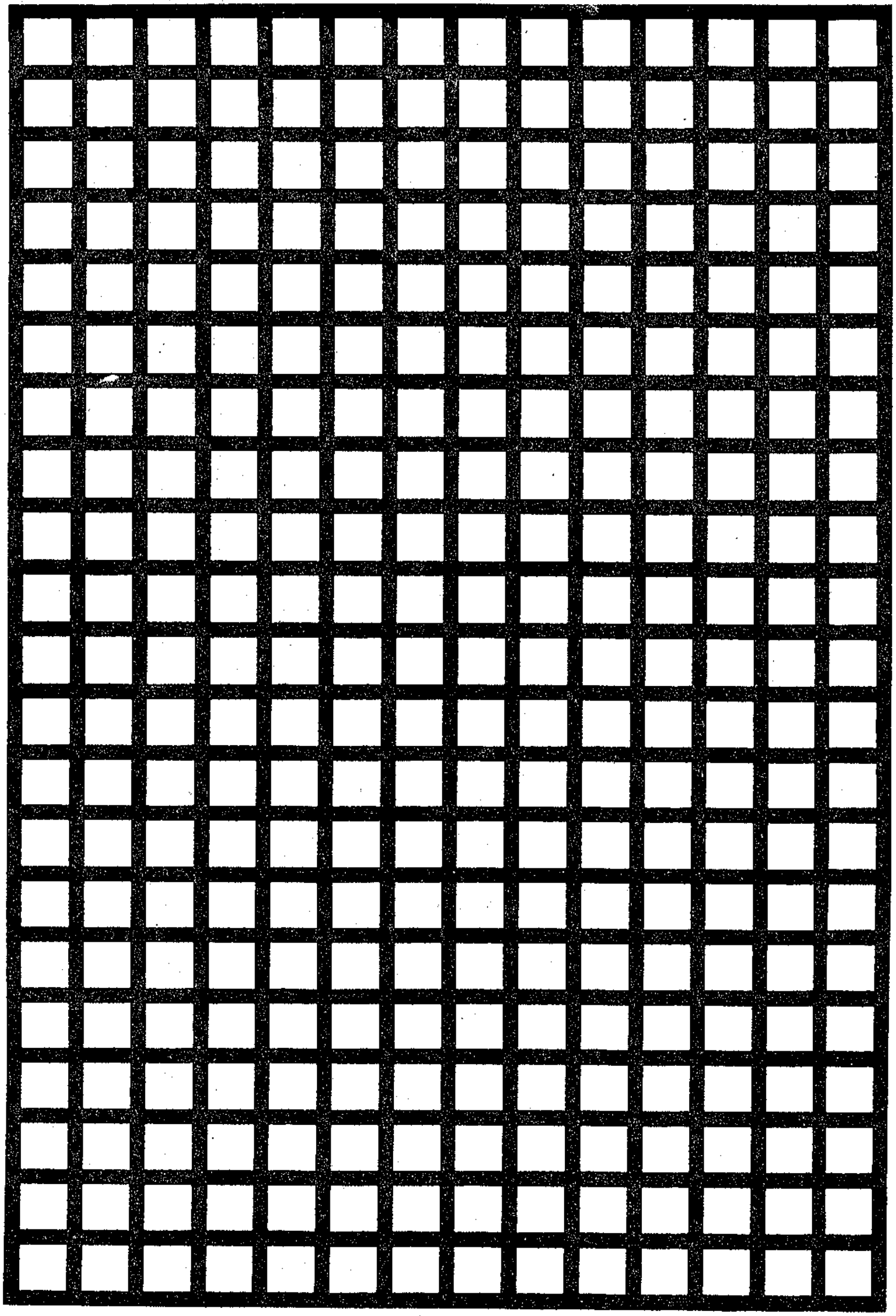
One of the first appearances of this concept may have been in air pollution control ordinances of the County of Los Angeles in 1945. In 1947 the Health and Safety Code of the State of California was amended to provide for the establishment of county-wide air pollution control districts. As already stated one section of this act limits visible emissions for a given period of time, not only to Ringelmann No. 2 shade of gray but also any visible emission of such opacity as to obscure an observers view to a degree equal to or greater than Ringelmann No. 2. Opacity simply means the degree to which transmitted light is obscured. Thus it is mandatory for any air pollution control district in California formed under this law to use the equivalent opacity concept. The Bay Area Air Pollution Control District, formed by a different enabling act, uses the same equivalent opacity concept.

Below is the relationship between Ringelmann number and opacity:

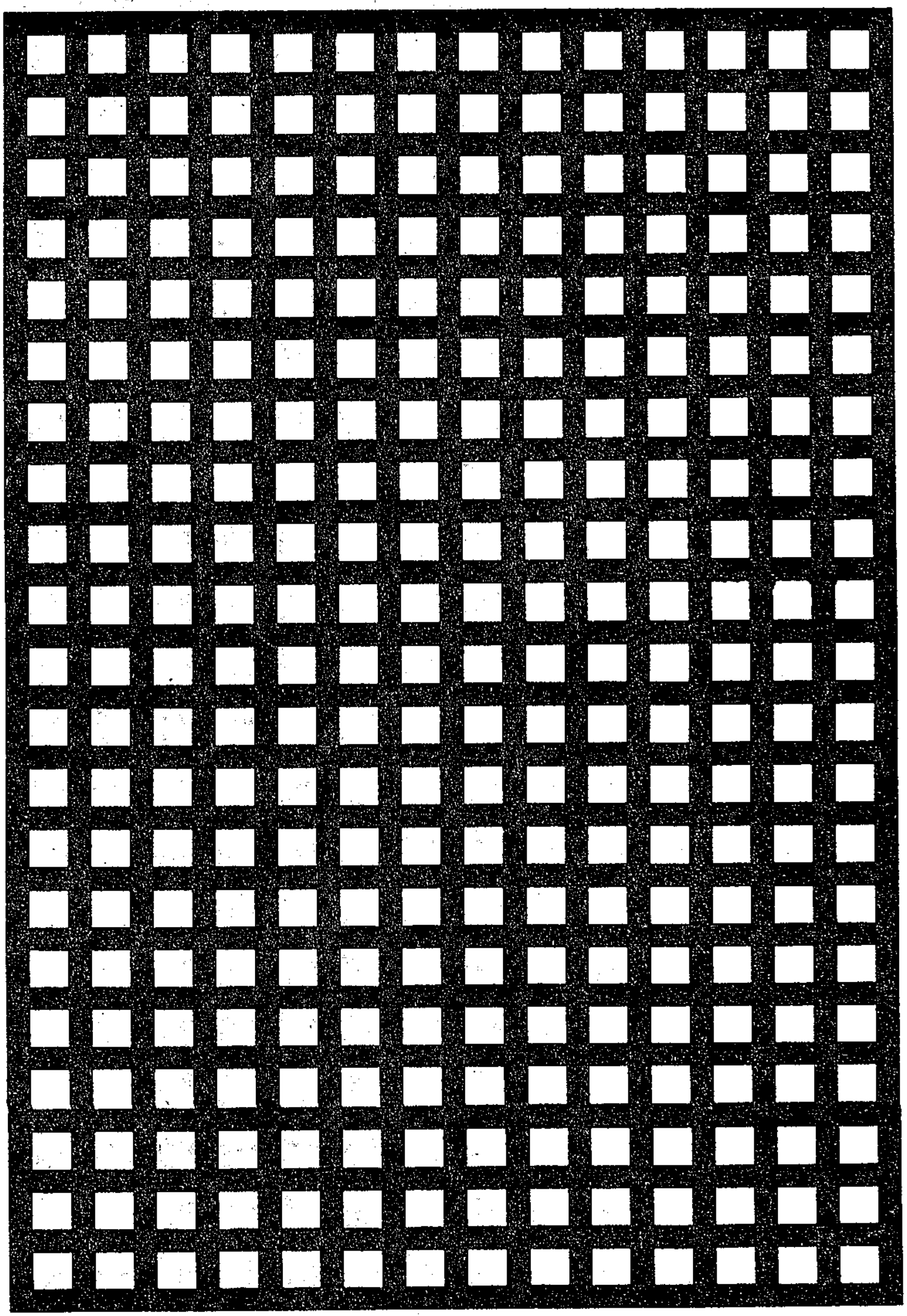
Ringelmann Number	Opacity Percent
1	20
2	40
3	60
4	80
5	100



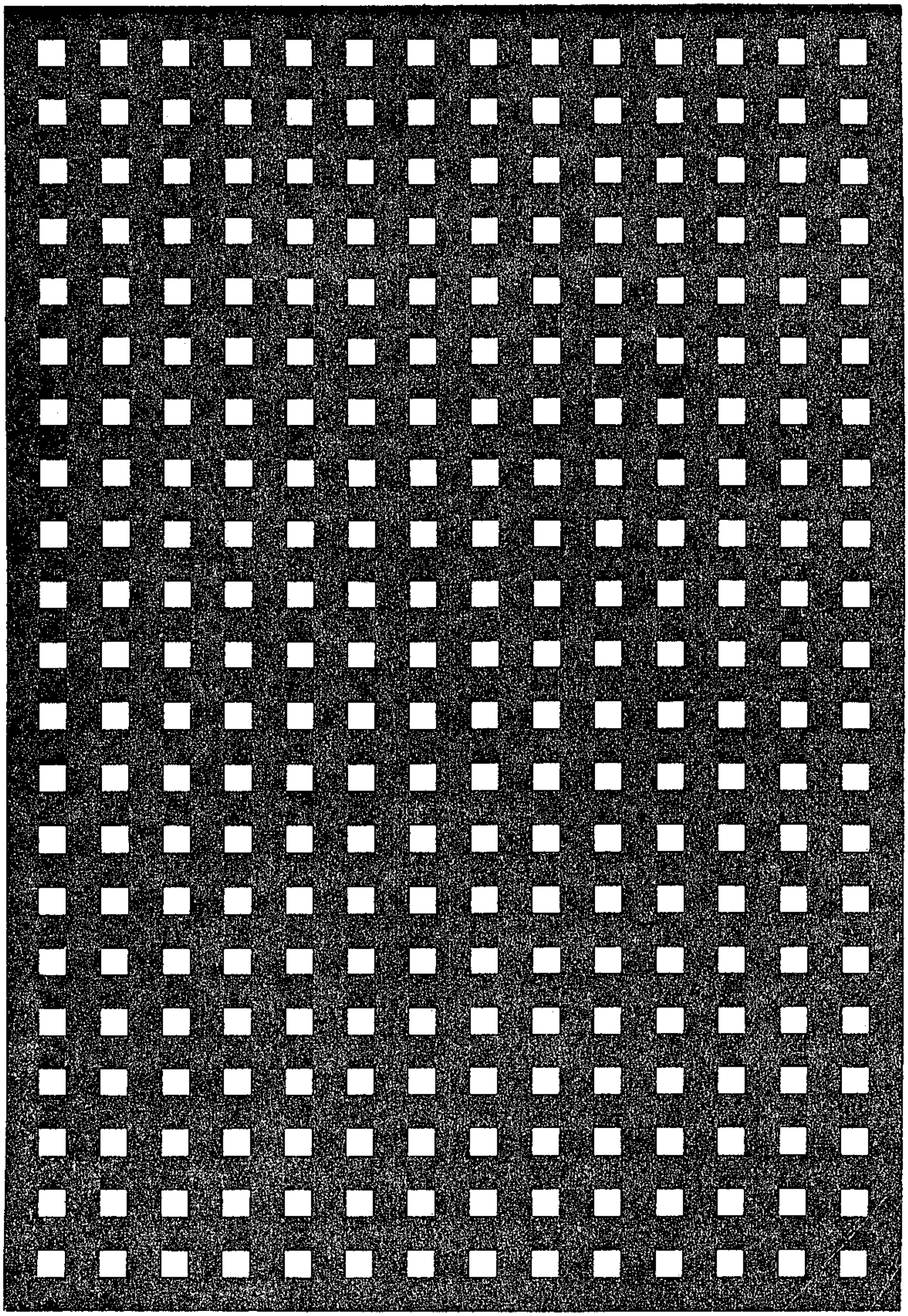
1. EQUIVALENT TO 20 PERCENT BLACK.



2. EQUIVALENT TO 40 PERCENT BLACK.



3. EQUIVALENT TO 60 PERCENT BLACK.



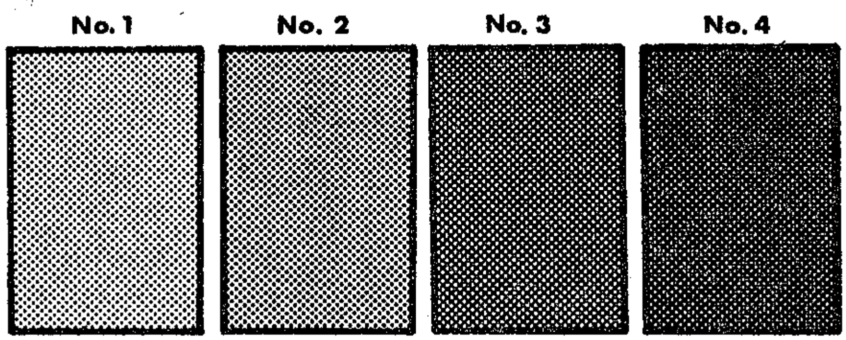
4. EQUIVALENT TO 80 PERCENT BLACK.

APPENDIX B

STATE OF CALIFORNIA
AIR RESOURCES BOARD

VISIBLE EMISSION EVALUATION

COURSE MANUAL



Ringelmann Chart

August 1970

can be performed in the field in a few minutes and provides two points from which both zero and span can be checked.

An absolute calibration of the up scale calibration point should be performed at least once each month. This is accomplished by filling the sample chamber with particle free Freon 12 gas and adjusting the meter Cal setting as necessary.

2. The mechanical weather station will be set up near the construction project where it will be representative of the wind flow at the construction site.

3. A reading will be taken upwind and out of the influence of the construction activity, for a minimum of 15 minutes.

NOTE: The nephelometer will be operated as described in Reference 8, "Monitoring of Atmospheric Aersol Parameters With the Integrating Nephelometer."

4. The nephelometer will be moved downwind of the construction activity between 50 and 300 feet from the edge of the activity.

5. Continuous readings will be taken for a minimum of 15 minutes.

6. Repeat steps 4 and 5 as often as necessary to obtain data representative of the dust transported from the construction site.

7. The highest reading for the test period will be determined and the average background reading subtracted. The highest readings for each one minute interval of the 15 minute continuous intervals will be averaged.

8. Report the highest reading minus the background average for each sampling interval and the highest 15 minute average minus the background average.

Precautions:

The calibration of the nephelometer should be checked before each day's sampling and after four hours of sampling, and at the end of the sampling period.

The nephelometer should be purged prior to beginning any sampling interval.

TEST METHOD 702*

METHOD FOR MEASURING FUGITIVE DUST TRANSPORTED FROM CONSTRUCTION SITES USING THE INTEGRATING NEPHELOMETER

SCOPE:

The procedure for measuring fugitive dust transported away from highway construction activities using an integrating nephelometer is described in this test method. The principle upon which this method is based is the scattering of light caused by the presence of aerosols and dust particles. The light scattering measurement is given in b-Scatter 10^{-4} m^{-1} units which is related to the wavelength of light from an xenon flash lamp.

PROCEDURE:

A. Apparatus

1. An integrating nephelometer (MRI or equivalent), preferably mounted in a vehicle.

2. A recording system compatible with the nephelometer.

3. A mechanical weather station capable of measuring wind direction and wind speed.

B. Materials

1. Chart paper, enough for 6 to 8 hours' operation.

C. Procedure

1. Before beginning operations the nephelometer should be purged and the calibration checked.

When calibrating the main air intake is closed and the sample chamber soon fills with particle-free purge air, the Rayleigh scattering coefficient of which is known and small. The instrument output then gives a calibration point at a very low scattering coefficient. To calibrate the higher ranges, the shutter at the end of the light trap is opened so that the multiplier phototube can view an illuminated white surface through a hole about 1 millimeter in diameter. This gives a second calibration point of about one-half scale on the most sensitive range of the instrument. This calibration

*Hypothetical Test Method Number

Where:

SP = mass concentration of suspended particulate, $\mu g/m^3$

W_i = initial weight of filters, g

W_f = final weight of filters, g

V = volume of air sampled, m^3 (be sure to make necessary changes for temperature, pressure, and flow rate)

10^6 = conversion of g to µg

12. Subtract background concentration from downwind concentration(s) and report results.

Precaution:

Wind regimes are subject to change, especially in the mid morning and early evening hours. These times should be avoided if possible, or provision made to change sampler filters and locations when testing is required during those periods.

2. The filters will be removed from the controlled environmental (humidity) chamber, weighed and prepared for transportation to the project without damage.

3. At the project site a mechanical wind station will be set up, unless a permanent one is available to determine wind speed and direction at the project site.

4. One high volume sampler will be placed in an area up wind and far enough away so that it will not be affected by dust from the construction activity.

5. A high-volume sampler will be placed directly downwind from the construction activity between 50 and 300 feet from the edge of the activity and not where it will interfere with the contractor's operation. If two samplers can be placed in this area it is preferable to use both.

6. The high-volume samplers are to be operated with a filter in place for a sample period of from one-half to eight hours or until there is a significant change in wind direction. The operation of the high-volume sampler is to be conducted in accordance with Intersociety Test Method 501 (11101-01-70T)(26).

7. Immediately after the sampling is completed the filters will be removed, folded in half, and returned to the glassine envelopes.

8. If desired the test can be repeated.

9. Upon completion of testing the filters will be removed from the envelopes and placed in the controlled environmental (humidity) chamber for 24 hours.

10. The filters will be weighed.

11. The average dust concentration will be calculated for the testing period using the equation:

$$SP = \frac{(W_f - W_i) \times 10^6}{V}$$

TEST METHOD 701*

METHOD FOR MEASURING FUGITIVE DUST FROM CONSTRUCTION SITES USING HIGH VOLUME SAMPLERS

SCOPE:

The procedure for measuring fugitive dust transported away from highway construction projects using high volume samplers is described in this test method. Dust concentrations can be determined at various distances from the construction activity.

PROCEDURE:

A. Apparatus

1. A minimum of two high volume samplers, but preferably four samplers, which meet the specifications of Part 5 of the Intersociety Committee Tentative Test Method 501 (11101-01-70T)(26).

2. A mechanical weather station capable of measuring wind direction and wind speed.

3. A balance or scale having a sensitivity of 0.1 mg and capable of weighing a 3"x10" (20.3x25.4 cm) filter.

4. An environmental chamber maintained at a constant temperature between 59°F (15°C) and 95°F (35°C) to within $\pm$2°F (1°C) and a particular relative humidity below 50 percent and to within $\pm$5 percent.

B. Materials

1. Filter media-glass fiber filters having a collection efficiency of at least 99 percent for particles of 0.3 micron diameter.

2. Glassine envelopes capable of holding an 8"x10" filter without folding.

C. Procedure

1. Enough filters will be placed in the controlled environmental chamber for 24 hours, to provide two filters for each high volume sampler for each day of sampling.

*Hypothethical Test Method Number

APPENDIX A

Test Methods for Measurement of Fugitive Dust

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17. "Fugitive particulate From Highway Construction," C. F. Kosky and M. P. Wanielista, Environmental Science and Engineering, Inc. and Florida Technological University, National Cooperative Highway Research Program Report, #75-36.3, 1975.

18. "Transportation and Air Pollution," Right of Way, August 1975, Vol. 22, No. 4.

19. "Total Anthropogenic Suspended Particulate as Derived from Chemical Analysis of Chloride and Silicate on High-Volume Samples," D. A. Levaggi, J. S. Sandberg, M. Felstein and S. Twiss, Journal of the Air Pollution Control Association, June 1976, Vol. 26, No. 6.

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10. "Calibration of the High-Volume Air Sampler", D. R. Lynam, J. O. Pierce and J. Cholak, American Industrial Hygiene Association Journal, Jan-Fed. 1969.

11. "Field Evaluation of the High-Volume Particle Fractionating Cascade Impactor--A Technique for Respirable Sampling," R. M. Burton, J. N. Howard, R. L. Penley, P. A. Ramsay and T. A. Clark, Environmental Protection Agency, Research Triangle Park, North Carolina, June 1972.

12. Particle Size Analysis, J. D. Stockham and E. G. Fochtman; Ann Arbor Science Publications, Inc., Ann Arbor, Michigan, Second Edition, 1978.

13. Fundamentals of Air Pollution, S. J. Williamson Addison-Wesley Publishing Co., 1973.

14. "Size Distribution Measurement of Particulate Matter In Los Angeles and Anaheim Using High-Volume Andersen Samplers," M. W. Wadley, S. Witz, W. Bope, and R. D. MacPhee, South Coast Air Quality Management District, Journal of the Air Pollution Control Association, April 1978, Vol. 28, No. 4.

16. "The Use of An Integrating Nephelometer for Monitoring Dust Nuisance at Highway Construction Sites," G. Bemis, D. Yeh, and R. M. Martin, California State University, Sacramento, Unpublished Report, May 1973.

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Considerable work is being done for control of wind erosion on soil that has been disturbed during construction. Three of the reports studied during this research project have excellent data on various types of spray-on materials (5). There are a wide variety of materials being applied for dust control, but not many are applicable to a temporary application. The economics of using these methods, however, are highly questionable because watering is apparently quite effective.

Future Work

Future research work is needed to correlate dust concentration to nephelometer readings for varying site and field conditions. A better correlation of drying conditions with dust generation and application of water or other dust palliatives is also needed. If better equipment can be obtained or if present equipment is improved, an extensive study should be made to determine the distribution of fugitive dust particle sizes and the distance the various sized particles are transported by winds of various velocities.

Mitigation

During this study the only mitigation method used for dust control was application of water. For most construction activities this method will continue to be the one most widely used since water is available in all areas, it has a very low initial cost, and it is required for compaction of soil. The contractor must establish a water source early in any construction project for compaction, therefore, it is only natural that he will apply water for dust control. It is a good method for controlling fugitive dust, however, the results are very temporary. The optimum watering interval required for good dust control varies with the drying conditions and the type of soil in the area.

It was noted that more dust is generated per pass by miscellaneous vehicles using unwatered sections of the highway grade than several passes of trucks on the haul roads. The solution to this problem is to require construction personnel and control agency personnel to use the watered haul road.

Other types of mitigation measures are being tried and several are used as standard practice. The most common, other than watering, is applying an asphaltic seal to areas where some construction activity has been completed and the area is scheduled to be used for traffic, or might be subjected to wind or water erosion. Another material which is widely used for dust control, especially on unpaved roads is calcium chloride. This material is not effective in dry climates and its use in California would be very limited.

During the monitoring it was noted that construction traffic operating outside the normal haul roads or areas of construction, where watering was being conducted, created large quantities of dust. These activities were short term and very temporary in nature, but control of these would enhance the reduction of fugitive dust. These activities included loading of material from stockpiles or waste areas which are not watered, and the travel of pickups or mechanic's trucks in median or shoulder areas.

In evaluating the data, one of the attempted correlations was that of wind speed to dust concentration. These data were plotted for analysis, but were so scattered that no correlation could be made. It is suggested that a greater amount of data for one specific construction activity could result in a correlation for a specific site.

As the quality of the haul road surface improves from embankment to lime treated subbase to lean concrete base, the amount of dust generated from hauling activities decreases significantly. Curing seal for treated subbase and base is very similar to material used for dust palliative and controls dust in addition to retaining moisture in the treated material.

In the urban environment the background dust levels were considerably higher than in the rural areas. This could be caused by many activities such as local traffic, grading for new developments, and resuspension of settled dust by wind. This higher background level would reduce the amount allowed to be generated by the contractor if specification limits were based only on total suspended particulate.

Temperature and relative humidity were measured during the study in an attempt to correlate dust generation with drying conditions; however, frequent watering made this type of correlation impossible. Further study seems needed in this area even though definitive results will be difficult and costly to obtain. A parameter that was obtained in conjunction with the use of hi-vol samplers early in the study was barometric pressure. These data were needed to determine the flow rate of air through the hi-vol samplers prior to installing automatic flow control devices.

General

There was a large volume of data generated from the activities monitored in this project. Much of these data were meaningful, but some were contradictory.

In the analysis, it became apparent that the control of fugitive dust on both projects was generally very good. The specifications were developed on the premise that the control achieved was adequate, with certain exceptions, and was of the level reasonably attainable by the construction industry. The resident engineer would be given authority for the enforcement of these specifications. Action, such as suspending operations until application of water or dust palliative is made, could be taken to correct a problem. If future monitoring indicates that tighter limits can be obtained or the limits indicated are too restrictive, they should be changed in accordance with those data.

Several unsuccessful attempts were made to correct the problem of large dusts passing through to the bottom filter. The first modification was to improve the seal between the Sierra Cascade Impactor on the top of the hi-vol sampler and attach a cyclone preseparator to the top of the cascade impactor. The latter device reduced the volume of air passing through the sampler but did not correct the problem.

It was suggested that the bottom filter be weighed as received and then reweighed after the obviously oversized particles were brushed from the filter. This was tried on several samples, but the large particles were difficult to dislodge; and even after brushing, the amount of particulate on the filter was in excess of 50 percent. Thus, this method was also determined to be ineffective.

Meteorological Considerations

No discussion regarding control or measurement of dust or other air pollutants could be complete without considering the measurement of meteorological conditions and variations. The most important parameters in studying dust transport are wind direction and wind speed. The amount of dust transported and the size of particulate suspended are related to wind velocity while wind direction determines the effect of the blowing dust on receptors such as residences, parks, crops, schools, or hospitals.

settle out readily and can stay airborne until they ampact something or are washed out of the atmosphere.

For the Bakersfield soil (classified as a fine sandy silt), more than 20 percent was less than 30μ and approximately 10 percent would be respirable. On the Stockton project, the soil was a silty clay with more than 40 percent less than 30μ and about 20 percent in the respirable range.

The first attempt to determine the dust particulate sizes was through the use of Andersen Impactors. Several problems with using Andersen Impactors are: (1) the large amount of air that must pass through the impactor to provide a measureable sample, (2) the long sampling times required do not coincide with the times when the construction activities occur, (3) the weight of the plates are far greater than the weight of the soil particles that settle out on them, and (4) the sensitive scales required for weighing the samples are not readily adaptable to field sampling. The data obtained were contradictory and gave no indication of the particulate sizes and amounts that were generated from the various construction activities.

The equipment which appeared to be the most adaptable to determining size distribution of dust particles for field use was the Sierra Cascade Impactor, but an unexpected problem occurred with the use of these impactors. The problem was that large dust particles were not being deposited on the proper filter but passed through to the bottom filter where they were caught along with the very fine particles. These larger particles were visually obvious on the filter and they collected near the corners of the area of the filter that was covered with dust.

readings indicating he is out of specifications and the engineer could suspend operations until the area is watered, a dust palliative is applied or some other suitable treatment is made. Further work is needed to develop the specification limits for nephelometer readings.

Particle Size Distribution

An objective of this study was to determine the particulate size distribution of the dust upwind and downwind of the construction activity, and the distance the various sizes were transported. The first effort was to determine the size distribution in the parent soil from which the dust would be generated. The ultimate correlation would have been a relation of dust transport and concentration with the size and type of particles on the surface of the disturbed soil. This correlation or even a satisfactory particulate size distribution in the dust proved unobtainable, at least with the equipment and methods utilized. Perhaps equipment designed for ambient air particulate size distribution is not practical for use where dust concentrations are extremely high and the particles are larger than normally encountered.

The portion of the soil sample we were most concerned with is that smaller than 30μ, which many investigators feel is the size that can be readily become airborne. For our purposes, that portion below 30μ can be considered the practical size that would be airborne for distances in excess of 50 feet. The portion smaller than 3.5μ is that portion which is respirable, and therefore a health hazard. The portion between 3.5μ and 30μ can be considered a nuisance. The very fine particles, less than 3μ, do not

(1) the equipment is very portable and can be mounted in a vehicle to make it mobile, (2) readings can be taken within three to five minutes after it is set up, (3) a recorder can be attached which gives a permanent record for enforcement and job files, (4) many activities can be monitored in a short time or at several locations along a project, and (5) it does not require 110-volt power to operate.

Like any sophisticated equipment there are disadvantages to its application, and some of these are: (1) the initial cost is three or four times that of a hi-vol sampler, (2) considerably more skill and training is required for operation and maintenance of the equipment, (3) the equipment is not as reliable as the hi-vol samplers, (4) there is considerably less experience with this type of equipment in field applications, (5) calibration of the equipment is more critical than with the hi-vol sampler, and (6) a technician should be present most of the time the equipment is in operation. Further work is required to develop a correlation between concentrations of airborne particulate and the nephelometer readings for particulate sizes encountered near construction activities. Then, conceivably this equipment could be the answer to quantifying many fugitive dust problems.

A tentative test method was developed for the nephelometer during this study and is included in the Appendix as Test Method No. 702.

The use of the nephelometer and specified limits would give the resident engineer a positive method for enforcing control of fugitive dust. The contractor could be shown

Undeveloped			Developed (residential & commercial)		
Distance Downwind		Concentration	Distance Downwind		Concentration
50 ft	-	500 μg/m^3	50 ft	-	250 μg/m^3
100 ft	-	450 μg/m^3	100 ft	-	225 μg/m^3
300 ft	-	300 μg/m^3	300 ft	-	150 μg/m^3
500 ft	-	200 μg/m^3	500 ft	-	100 μg/m^3

The test method has been given a hypothetical number of 701 and appears in Appendix A. The tentative specification limits are plotted on Figures 13, 14, 15 and 16 so that they can be compared with actual measured values.

Both projects monitored were able to maintain specified dust concentration levels most of the time. This indicates that the standards established are realistic and can be met without an excessive hardship on the contractor.

These values were chosen because they were attainable when the contractor was doing a satisfactory job of dust control. The rural and urban specifications were based on the two jobs that were monitored and seem reasonable since a much greater number of people are exposed to the nuisance of dust in an urban community.

Integrating Nephelometer

A device which was used only in the latter stages of the study is the integrating nephelometer. This tool appears to have considerable potential in the enforcement of specifications regarding control of fugitive dust from construction projects and perhaps from unpaved roads. There are several advantages in using this equipment. They are:

transport distances from the source. The hi-vol sampler was chosen because it is the tool referred to for measuring the amount of suspended particulate to determine compliance with the National Ambient Air Quality Standards.

There are several advantages in using a hi-vol sampler: (1) relatively low cost, (2) a competent technician can be taught to use the equipment with a minimum of training, (3) the equipment is simple to operate, (4) it is very reliable and not subject to breakdown and malfunctions, and (5) it has a high degree of precision (9). The disadvantages are: (1) the required time of one or two days to condition and weigh filters for analysis, (2) the need for a source of electrical power, (3) the visibility of sampling equipment to construction personnel, and (4) the time required to set up samplers. This method of control is after-the-fact since it takes at least 24 hours, or more reasonably 48 hours, after the dust is generated until the levels of the dust concentrations are determined.

Tentative specifications based on measured concentrations and subjective observations by an engineer experienced with measurement of fugitive dust concentrations have been developed. These tentative specifications were developed for contract control using hi-vol samplers, and are as follows:

> "The amount of dust generated by any of the Contractor's activities shall be controlled so that a sample taken directly downwind of the operations with a high volume sampler shall not exceed the background concentration by any of the below listed concentrations when a four (4) hour sample is obtained as determined by Calif. Test 701."

DISCUSSION

The testing program for this project focused on finding a procedure for monitoring fugitive dust. Test methods for use in providing an effective contract specification enforcement tool were also sought, as was the establishment of quantitative specification limits. Tentative limits (in the following sections) were established by a trained engineer subjectively identifying unacceptable dust concentrations and comparing these concentrations to the obtained measurements.

Various problems that occurred during the program were unexpected at the outset. One was the fact that intensified watering occurred in the areas where the hi-vol samplers were set up even though it was made clear at the beginning of monitoring for each job that the data were strictly for research and would in no way be part of the contract control program. Other problems were experienced such as wide variations in meteorological conditions on each project and rapid changes in construction activity at the sampling locations. Another problem was the inability to accurately measure particulate sizes and quantities with commercially available state-of-the-art sizing equipment.

The problems encountered made the data analysis and direct comparisons difficult. From the data obtained, however, it was possible to develop some tentative specifications and test methods using the various dust monitoring devices.

High Volume Sampler Specification

The testing program began using high volume samplers to measure the concentrations of fugitive dust at various

It is apparent from these data that watering was used extensively as a dust control measure on this construction project. Water trucks passed the monitoring site at approximately 20 minute intervals which resulted in relatively low readings. The high readings shown in Figure 18 for under 5 minutes were attributed to water spray interference with sensor.

Based on the nephelometer readings for this project it appears that watering at 20 minute intervals was an effective control of dust generation during these two construction activities. The amount and timing of water applications for dust control is dependent upon soil type or surfacing, climatic conditions, frequency of truck passage and etc. Because of these variables, watering intervals must be determined on an individual basis for each activity.

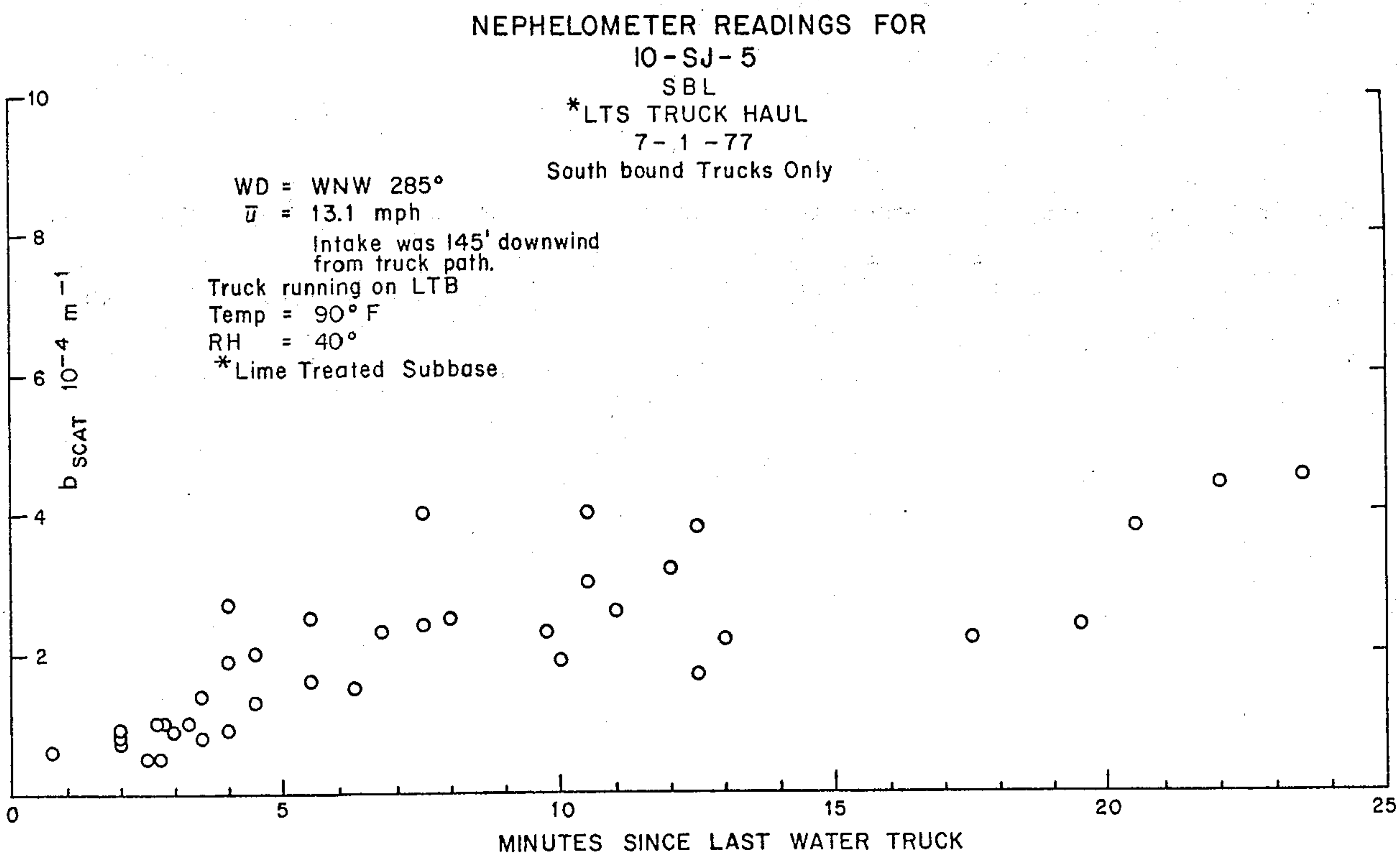


Figure 20 - Integrating nephelometer readings for southbound trucks hauling on lime treated subbase, compared to time since watering.

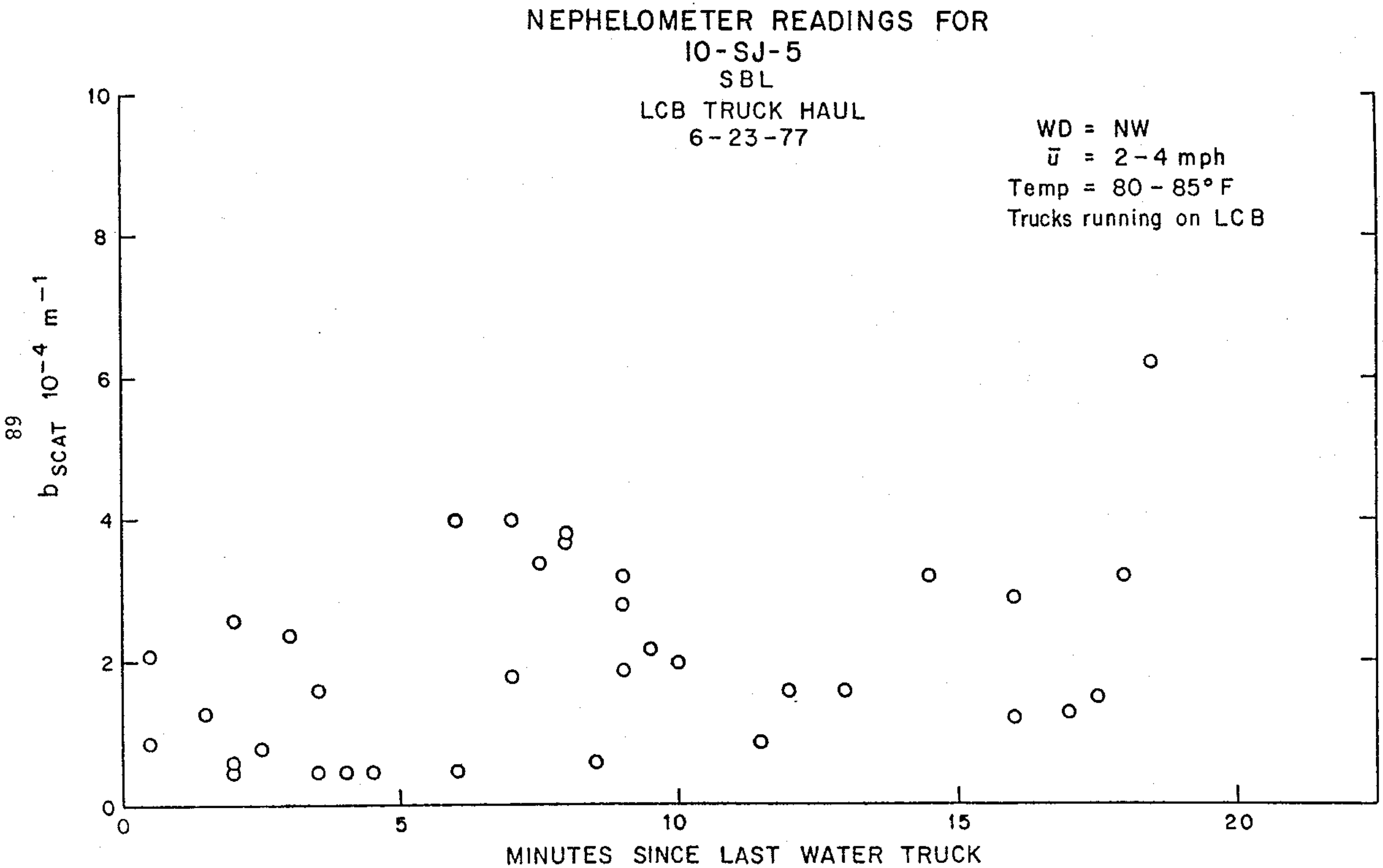


Figure 19 - Integrating nephelometer readings for dust generated from trucks hauling on lean concrete base, compared to watering time.

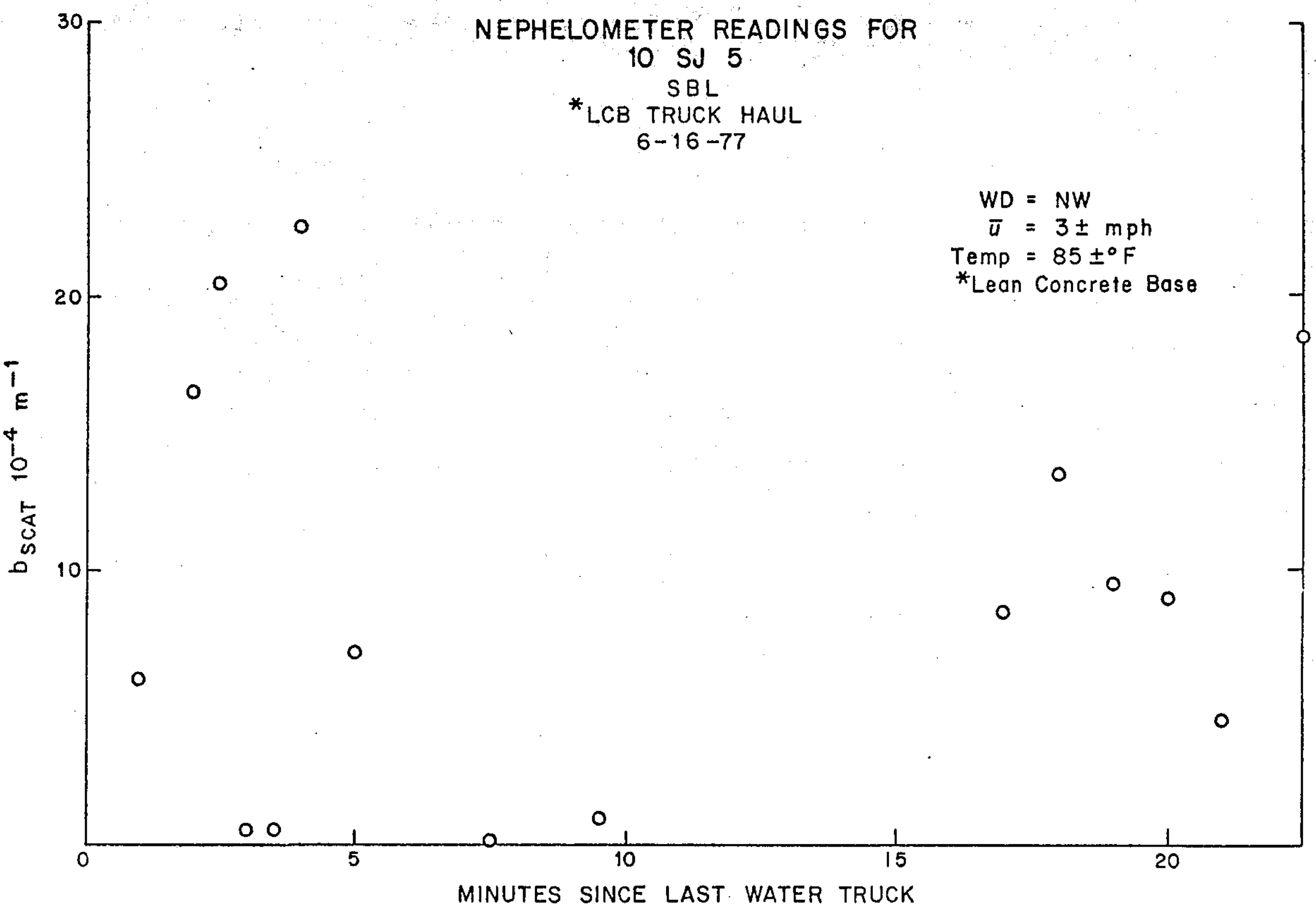


Figure 18 - Integrating nephelometer readings for dust generated from trucks hauling on lean concrete base, compared to watering time.

3. Stockton

For the sampling on the Stockton project, there were several variations from the techniques used at Bakersfield. There was also some experimentation to develop a specification for enforcement.

During May, 1977, the nephelometer was used in a limited attempt to develop a pattern of typical readings to correlate with visible emission readings. These measurements were taken during the activities of lime treated subbase trimming, and trucks traveling on haul roads composed of lime treated base and lean concrete base. Measurements ranged from 7 to $9x10^{-4}$ m^{-1} for 30 percent opacity and $3.0x10^{-4}$ m^{-1} for 10 percent opacity. The number of observations was too small for a conclusive analysis.

During trimming operations in June, 1977, the 100 ft downwind nephelometer reading was 9.5 to $7.0x10^{-4}$ m^{-1} compared to a background reading of $0.25x10^{-4}$ m^{-1}. This was a worst case as subsequent readings were in range of $3.3x10^{-4}$ m^{-1} to $1.5x10^{-4}$ m^{-1}.

Three more test days followed. The construction operation was unchanged. Haul trucks were using the lean concrete base northbound and the lime treated base southbound. Readings were taken with regard to the time of the last water truck passage. The data are plotted in Figures 18, 19 and 20.

TABLE 9

NEPHELOMETER READINGS

b-Scatter 10^{-4} m^{-1} Scale

Bakersfield

Date	Average Reading	Standard Deviation	High Reading	Low Reading	Corres. Hi-Vol Conc. $\mu g/m^3$
6-8-76	0.57	0.081	1.55	0.38	179
6-9-76	0.59	0.076	1.48	0.42	184

Stockton

Date		Average Reading	Standard Deviation	High Reading	Low Reading
6-2-76		0.46	0.287	3.05	0.20
6-6-76		11.7	10.21	55	1.0
6-16-77	NBL*	10.0	8.75	33	0.1
	SBL*	8.4	7.21	22.5	0.5
6-23-77	NBL*	5.1	1.90	7.5	1.2
	SBL*	2.0	1.34	6.2	0.5
7-1-77	NBL*	1.84	0.54	2.7	0.9
	SBL**	2.07	1.19	4.5	0.5

*Lean Concrete Base

**Lime Treated Subbase

The equation recommended in the literature (17,18) for calculating the dust concentration from the b-scatter coefficient is, in a simplified version:

$$MASS = 3.8 \times 10^5 \, b_{scat}$$

Where: MASS is in $\mu g/m^3$
b_{scat} is in m^{-1} and is the scattering coefficient due to aerosols in the atmosphere.

2. Bakersfield

The first tests with the nephelometer to sample dust during a construction activity were made during the last two days of testing on the Bakersfield project.

The nephelometer was operated in conjunction with other sampling devices and was placed near the second downwind hi-vol sampler 300 feet from the haul road. The nephelometer readings are picked off a chart to give a reading each minute. A segment of chart is shown in Figure 17. These readings were averaged over 15-minute intervals. Dust concentrations were relatively low on this date. The readings varied from a high of 1.55×10^{-4} m^{-1} at 0945 to a low of 0.38×10^{-4} m^{-1} at 1427 with an average of 0.57×10^{-4} m^{-1} for the 4 hours and 55 minutes that the nephelometer was in operation. The corresponding hi-vol concentration was 179 $\mu g/m^3$ (Table 9).

Sampling on the following day with the nephelometer was done at the second downwind location along Berneta Avenue. The dust concentrations on this date were slightly higher than the preceding day. The average reading was 0.59×10^{-4} m^{-1} for 5-1/4 hours. The corresponding hi-vol value was 184 $\mu g/m^3$.

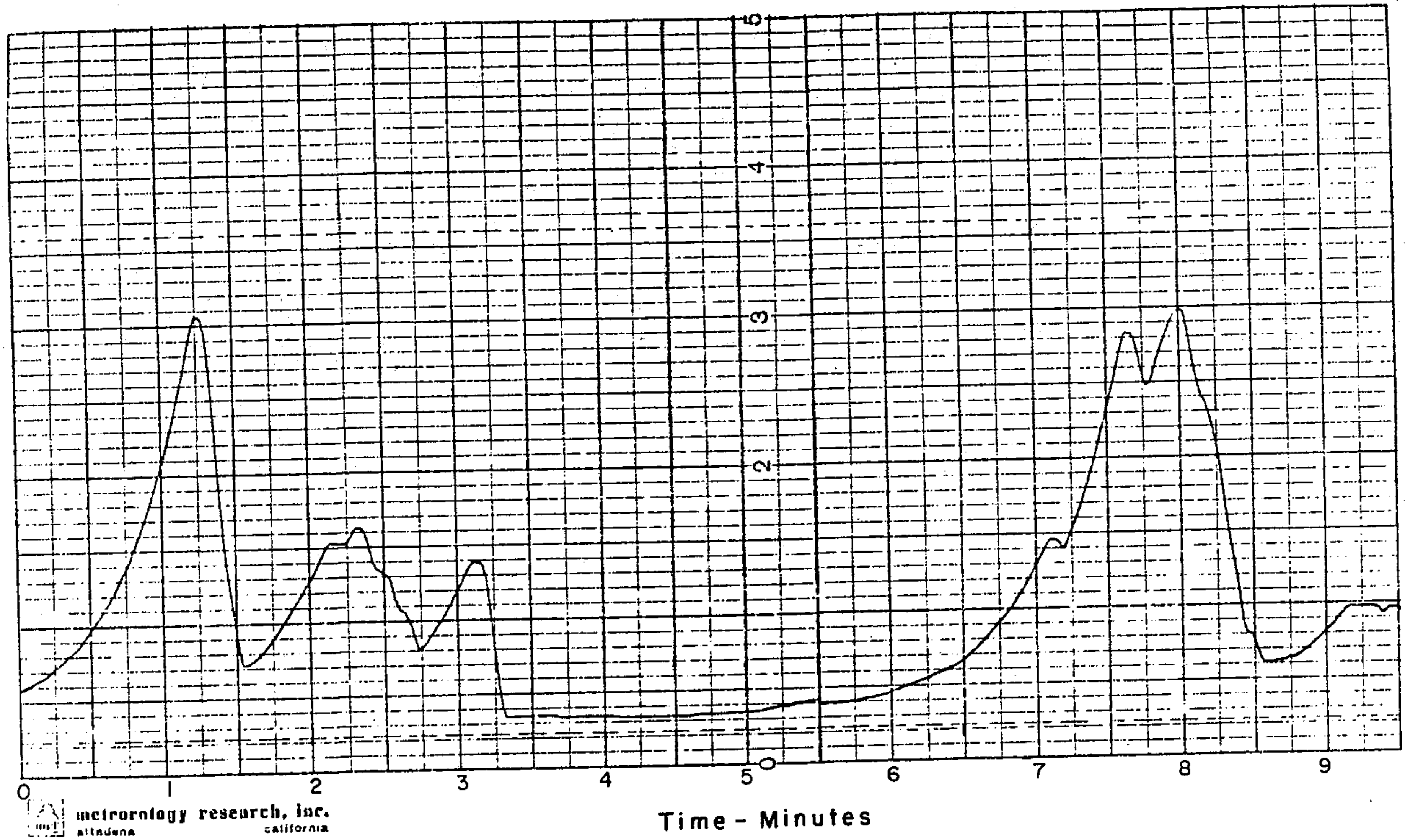


Figure 17 - A typical section of chart from an integrating nephelometer. The ordinate is b_{scat} 10^{-4} m^{-1} units and the absicissa is time.

the aluminum pipe into the optical unit. A light in the optical unit flashes at a designated rate. The intensity of the flash is monitored directly across from the light and the intensity of the scattered light is measured perpendicular to the path of the light beam. The electronic components within the instrument convert these measurements to obtain the scattering coefficient.

The nephelometer provides an instantaneous reading and does not require a long set-up time or weighing of filters which has to be done away from the job site. It can be attached to a chart to develop a permanent record (Figure 17) for the project files. These features provide many characteristics of an ideal tool for providing control of dust on a construction project involving large volumes of earthwork and miles of area where activity can occur.

That the nephelometer is useful is indicated by some preliminary correlation work between the nephelometer and the high volume sampler previously conducted by Caltrans and Sacramento State University students in a cooperative research activity. The results of this study are documented in an unpublished report titled "The Use of an Integrating Nephelometer for Monitoring Dust Nuisance at Highway Construction Sites" (16). The conclusions in that report indicate that a valid relationship exists between the dust concentration and the scattering coefficient as obtained at a given distance from a source with a particular particle size distribution. Variations had to be made to the dust concentration as calculated using the manufacturer's recommended equation and the b-scatter coefficient (defined as the reciprocal of the distance in which 63% of the light is lost from a light beam) to obtain the relationship.

The typical comparable total dust sample weights were: Hi-vol; 499 $\mu g/m^3$; Cascade; 501 $\mu g/m^3$; and the Cascade with preseparator; 160 $\mu g/m^3$. All three sample days were in this pattern. It was concluded that some impaction and collection of large particles was occurring in the pre-separator housing. This would explain the large discrepancy of that sample versus the others.

In theory the cascade impactor would be an excellent tool for a research study of the type described in this report.

Integrating Nephelometer

1. General

This part of the study was intended to compare fugitive dust particle size with the amount of extremely fine material present in the parent soil, and to determine which receptor areas were subjected to nuisance dust and respirable dust, and which receptors were subjected to respirable dust only.

The most promising tool for use in measuring the concentration of fugitive dust and providing enforcement of specifications, surprisingly, turned out to be the integrating nephelometer. The integrating nephelometer is a completely self-contained, continuously operating unit. For this study, it was bolted into a station wagon with the optical unit horizontal. A flexible hose passed out the rear window and was attached to a 1-3/4" aluminum pipe bolted parallel to the top of the car. An extra battery and an inverter mounted in the station wagon provided the power for the system. The particles are drawn through

TABLE 8 (Cont'd)

PARTICLE SIZE DISTRIBUTION AS
MEASURED WITH SIERRA CASCADE IMPACTORS
WITH AND WITHOUT PRESEPARATION

Stockton - Atherton Road 7-22-77 (Hi-Vol - 468 μg/m^3)

Without Preseparator

Stage	Size (μ)	ΔW (g)	μg/m^3	% Retained
1	>7.2	0.0043	21	5
2	3.0-7.2	0.0042	21	5
3	1.0-3.0	0.0031	15	4
4	0.95-1.5	0.0034	17	4
5	0.49-0.95	0.0025	12	3
Hi-Vol	<0.49	0.0680	333	79
Total			419	

With Preseparator

Stage	Size (μ)	ΔW (g)	μg/m^3	% Retained
1	>7.2	0.0025	12	8
2	3.0-7.2	0.0034	17	11
3	1.5-3.0	0.0028	14	9
4	0.95-1.5	0.0022	11	7
5	0.49-0.95	0.0019	9	6
Hi-Vol	<0.49	0.0176	86	58
Total			149	

TABLE 8 (Cont'd)

PARTICLE SIZE DISTRIBUTION AS
MEASURED WITH SIERRA CASCADE IMPACTORS
WITH AND WITHOUT PRESEPARATION

Stockton - Van Ruiten Road   8-8-77 (Hi-Vol - 277 $\mu g/m^3$)

Without Preseparator

Stage	Size (μ)	ΔW (g)	$\mu g/m^3$	% Retained
1	>7.2	0.0050	23	9
2	3.0-7.2	0.0038	17	6
3	1.5-3.0	0.0034	15	6
4	0.95-1.5	0.0027	12	5
5	0.49-0.95	0.0022	10	4
Hi-Vol	<0.49	0.0419	189	71
Total			262	

With Preseparator

Stage	Size (μ)	ΔW (g)	$\mu g/m^3$	% Retained
1	>7.2	0.0014	6	4
2	3.0-7.2	0.0020	8	6
3	1.5-3.0	0.0014	6	4
4	0.95-1.5	0.0012	5	4
5	0.49-0.95	0.0013	5	4
Hi-Vol	<0.49	0.0255	105	78
Total			135	

TABLE 8

PARTICLE SIZE DISTRIBUTION AS
MEASURED WITH SIERRA CASCADE IMPACTORS
WITH AND WITHOUT PRESEPARATION

Stockton - Van Ruiten Road 7-19-77 (Hi-Vol - 499 $\mu g/m^3$)

Without Preseparator

Stage	Size (μ)	ΔW (g)	$\mu g/m^3$	% Retained
1	>7.2	0.0026	9.8	2
2	3.0-7.2	0.0038	14.4	3
3	1.5-3.0	0.0034	12.9	3
4	0.95-1.5	0.0052	19.7	4
5	0.49-0.95	0.0049	18.6	4
Hi-Vol	<0.49	0.1129	426	85
Total			501	

With Preseparator

Stage	Size (μ)	ΔW (g)	$\mu g/m^3$	% Retained
1	>7.2	0.0028	10.7	7
2	3.0-7.2	0.0032	12.3	7
3	1.5-3.0	0.0026	10.0	6
4	0.95-1.5	0.0016	6.1	4
5	0.49-0.95	0.0004	1.5	1
Hi-Vol	<0.49	0.0311	119	74
Total			160	

3. Stockton

The sampling on the Stockton project was performed with various impactors but a conclusive analysis was not possible, therefore the sampling results are discussed only briefly. The results were similar to the Bakersfield analysis except that the concentrations sampled were considerably higher.

Only two trials using the cascade impactors were made at Stockton. With very high dust concentration, the total loading measured using the cascade impactor was only about two-thirds that determined with the hi-vol sampler during concurrent sampling. A very high percentage of particulate was carried through the bottom filter. This was in the range of 75 to 80 percent.

At this stage of the study, attempts to compare downwind particulate size distributions with background size distributions were abandoned. The testing was changed to set three hi-vol samplers within close proximity of the right-of-way line. One sampler was a hi-vol unit only, the second was a hi-vol fitted with a cascade impactor and the third sampler had a cyclone preseparator placed above the cascade impactor on the hi-vol (Figure 6).

Again at Stockton it was hoped that the preseparator would remove the particles larger than 7.3μ in order to permit the cascade impactor to operate as intended. As before, the trials were not successful. The data for sampling using cascade impactors with and without cyclone preseparators are shown in Table 8.

2. Bakersfield

The initial applications of a hi-vol with a Sierra Cascade Impactor were primarily to attempt a correlation with the unmodified hi-vol. Because the dust concentrations at the Bakersfield project were very close to ambient levels, the correlation was not acceptable. The total particulate measured with the cascade impactors did not agree with the hi-vol samples very closely. The problem with the large amount of particulate that accumulates on the bottom filter is evident from the data presented with 77 percent on the bottom filter of the downwind sampler and 83 percent for the background sampler. Microscopic comparison revealed that the particles that collected around the periphery of the bottom filter were much larger than those in the interior of the filter.

On the succeeding applications of the cascade impactors, the correlation with the hi-vol sampler improved to the range of 92 to 95 percent of hi-vol sample weight. In addition, there was a good particle size correlation between the background and downwind impactors, within 2 percent on each stage filter. The percentage of the sample on the bottom filter was 58 for the downwind impactor and 59 for the background. As expected, a decrease in sample size resulted in a proportional decrease in amount retained on each filter.

After completion of the testing at Bakersfield, it was felt that the cascade impactor sampling had promise for determining dust particulate sizes. However, the problem of the large percentage of the sample passing through to the bottom filter remained to be solved. The later testing at Stockton was based on the premise which proved erroneous, that this problem could be solved and that all collected data could be analyzed.

TABLE 7 (Cont'd)

PARTICLE SIZE DISTRIBUTION AS

MEASURED WITH SIERRA CASCADE IMPACTORS

Bakersfield - Berneta Avenue 6-9-76 (PCC Hauling & Placing)

Stage	Size (μ)	ΔW (g)	$\mu g/m^3$	% Retained
1	>8.2	0.0047	14	8
2	3.4-8.2	0.0048	15	8
3	1.7-3.4	0.0029	9	5
4	1.1-1.7	0.0025	8	4
5	0.6-1.1	0.0018	6	3
Hi-Vol	<0.6	0.0422	129	72
Total			181	

Bakersfield - Pacinis' Background 6-9-76

1	>8.2	0.0047	11.4	9
2	3.4-8.2	0.0045	10.9	9
3	1.7-3.4	0.0025	6.1	5
4	1.1-1.7	0.0021	5.1	4
5	0.6-1.1	0.0018	4.2	4
Hi-Vol	<0.6	0.0341	82.1	69
Total			122	

TABLE 7 (Cont'd)

PARTICLE SIZE DISTRIBUTION AS

MEASURED WITH SIERRA CASCADE IMPACTORS

Bakersfield - Houchin Road 6-8-76 (PCC Paving) 6 hour sample

Stage	Size (μ)	ΔW (g)	μg/m^3	% Retained
1	>8.2	0.0065	24.6	11.5
2	3.4-8.2	0.0067	25.2	11.9
3	1.7-3.4	0.0044	16.7	7.8
4	1.1-1.7	0.0037	14.0	6.5
5	0.6-1.1	0.0027	10.2	4.8
Hi-Vol	<0.6	0.0325	123.1	57.5
Total			214	100.0

Bakersfield - Pacinis Background 6-8-76

1	>8.2	0.0110	22.4	12.0
2	3.4-8.2	0.0100	20.3	11.0
3	1.7-3.4	0.0065	13.2	7.1
4	1.1-1.7	0.0055	11.2	6.0
5	0.6-1.1	0.0044	8.9	4.8
Hi-Vol	<0.6	0.0539	109.6	59.0
Total			186	

TABLE 7 (Cont'd)

PARTICLE SIZE DISTRIBUTION AS

MEASURED WITH SIERRA CASCADE IMPACTORS

Bakersfield - Berneta Avenue 5-4-76 (CTB Hauling & Placing)

Stage	Size (μ)	ΔW (g)	$\mu g/m^3$	% Retained
1	>8.2	0.0054	15.9	7
2	3.4-8.2	0.0047	13.8	6
3	1.7-3.4	0.0031	9.1	4
4	1.1-1.7	0.0027	7.9	4
5	0.6-1.1	0.0012	3.5	2
Hi-Vol	<0.6	0.0571	168	77
Total			218	

Bakersfield - Pacinis Background 5-4-76

1	>8.2	0.0045	9.8	8
2	3.4-8.2	0.0051	11.1	9
3	1.7-3.4	0.0037	8.0	7
4	1.1-1.7	0.0030	6.5	5
5	0.6-1.1	0.0018	3.9	3
Hi-Vol	<0.6	0.0390	84.6	68
Total			124	

TABLE 7

PARTICLE SIZE DISTRIBUTION AS

MEASURED WITH SIERRA CASCADE IMPACTORS

Bakersfield - Houchin Road 5-3-76 (CTB Hauling & Placing)

Stage	Size (μ)	ΔW (g)	$\mu g/m^3$	% Retained
1	>8.2	0.0025	9.2	10
2	3.4-8.2	0.0018	6.6	7
3	1.7-3.4	0.0011	4.0	4
4	1.1-1.7	0.0004	1.5	2
5	0.6-1.1	0.0001	0.4	0
Hi-Vol	<0.6	0.0192	70.6	77
Total			92.4	

Bakersfield - Pacinis Background 5-3-76

1	>8.2	0.0017	5.1	7
2	3.4-8.2	0.0015	4.5	6
3	1.7-3.4	0.0009	2.7	4
4	1.1-1.7	0	0	0
5	0.6-1.1	0	0	0
Hi-Vol	<0.6	0.0204	61	83
Total			73.3	

the upper filters as would be expected, but were passing through to the bottom filter which does not have the slotted passages. It is concluded that the larger particles bounce on impact and carry through to lower stages. Since the cascade impactor did not do the job, a tedious microscopic analysis would have been needed to distinguish large-size particles from the smaller sizes (0.3μ).

Several ideas were tried to solve this pass-through problem since the cascade device seemed to be an excellent method of determining total particulate concentrations and the particle size distributions within the same sample. Basically, the cascade impactor is attractive because it is not difficult to use and analysis is fast and relatively easy.

The first attempt to solve the problem was to improve the quality of gaskets used between each stage and between the cascade impactor and the top of the hi-vol. This did not noticeably change the amount of large particulate on the bottom filter indicating that the original gaskets provided an adequate seal. The next attempt was to reduce the flow rate of the air through the sampler. This also proved not to be a solution.

The final trials were to purchase and use a cyclone pre-separator which is designed to settle out the larger particles before they enter the filter stack. This seemed to partially solve the problem, but not enough to permit an accurate analysis of the particle size distribution. The test data obtained are included as Table 7 only to provide a complete study documentation. The author spent many hours attempting to analyze these data without success. The amount of oversize particulate which passed into and through the filter stack was an overwhelming factor, as can be seen in Table 7.

a larger and more meaningful sample. The hi-vol samplers on both days indicated relatively high dust concentrations. The sample weights from the Andersen Impactors increased only slightly from the previous trip with the total sample weight increasing from 0.0100 to 0.0138 gm. This was considerably below the sample size increase expected and not large enough to analyze.

On May 3, 1976, Andersen Impactors were again used on the Bakersfield project. The downwind sampler was placed on a table near the hi-vol sampler at the right-of-way line at Houchin Road (Figure 7). The Andersen Impactor was set at the same height as the inlet for the hi-vol sampler. The construction activity on this date was hauling, placing, and trimming of cement treated base. There was little dust generated during this operation as observed visually and measured with the hi-vol samplers. The largest sample was obtained at the background site which did not correlate with the hi-vol sample data. Andersen Impactor testing was discontinued for this study after this date.

Cascade Impactors

1. General

After the problems with the Andersen Impactors became evident, other methods of determining particle sizes of the transported particulate were sought. A method which appeared to have promise was the use of cascade impactors which could be attached to the top of the hi-vol samplers. This sampling method proved to be as frustrating as the Andersen Impactors. The primary cause of the frustration was that large dust particles were not being deposited on

Since the background dust concentrations in Bakersfield are significantly higher, they had a much greater effect on the total measured concentrations than those at Stockton. This may have a tendency to mask the lower amount of fugitive dust generated by the construction activity. It is a variable that was not predictable prior to analyzing the test data. The average background dust concentration at Bakersfield was 197 $\mu g/m^3$ as compared to an average of 108 $\mu g/m^3$ for Stockton.

Andersen Impactors

The most frustrating and disappointing part of this project was the attempt to determine particle sizes of the fugitive dust. The first attempt to quantify particulate matter according to size was with the use of Andersen Impactors on the Bakersfield project. The results were so disappointing and sampling so time-consuming that it was abandoned prior to beginning the Stockton Project.

The Andersen Impactors were run for 24 hours from the morning of August 14 to the morning of August 15, 1975. The construction activity on this date was excavation and hauling with large scrapers. The dust, as measured by the hi-vol samplers on Houchin Road, indicated high concentrations for both the morning and afternoon. The wind was from the northwest at 3 to 8 mph, which should have been a favorable sampling situation. The net sample taken even under this favorable condition was too small to be accurately analyzed.

On the trip to Bakersfield on August 26, 27 and 28, 1975, it was believed that a 48-hour sampling period would produce

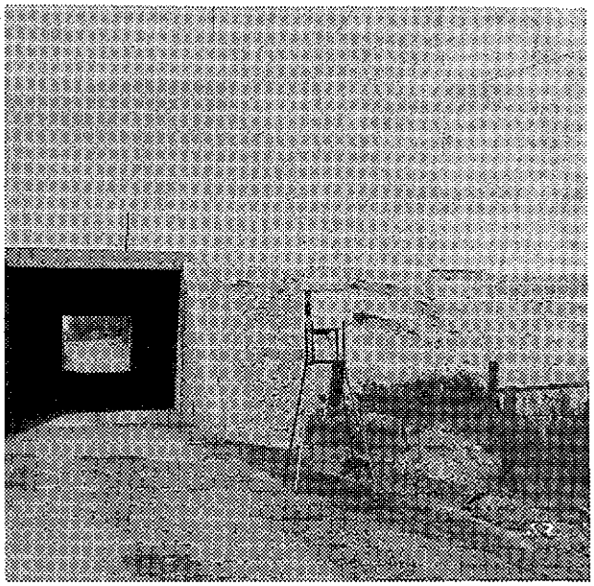


Fig. 15 - Van Ruiten Road on I-5 near Stockton looking west through the equipment undercrossing. Hi-vol sampler #1 in foreground.

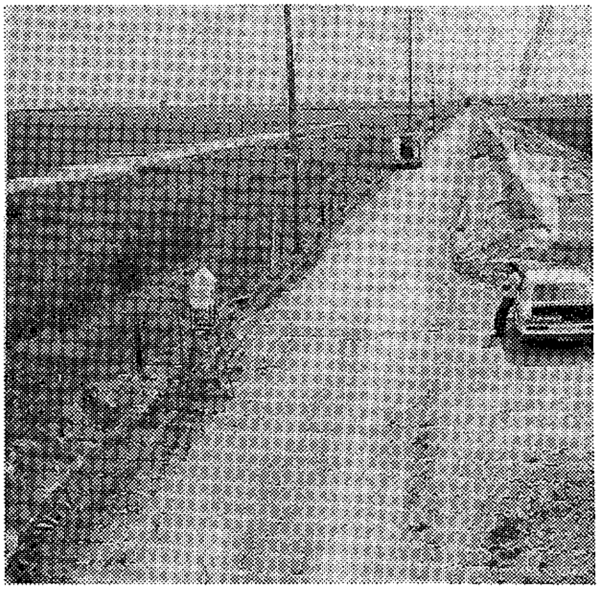


Fig. 16 - Van Ruiten Road with hi-vol samplers in place. Standing on top of equipment undercrossing looking east.

The watering on this project was extensive and dust levels reflected this. Even so, the highest dust levels recorded during this research project were measured at the Stockton site. These levels were attributed to miscellaneous construction support traffic using the grade outside of the haul roads. The mechanics trucks, supervisory personnel's pickups, etc., raised extreme amounts of dust for short periods of time near the sampling sites.

In addition, the embankment site was near an undercrossing (a farmer equipment tunnel, Figure 15) which was constructed tefore the sampling period was completed. This undercrossing may have acted like a wind tunnel to disperse the windblown dust to the downwind samplers. It was at this site that the highest level (1,092 $\mu g/m^3$) was recorded (Table 5).

For the at-grade section, the downwind concentrations ranged from a low of 135 $\mu g/m^3$ to a high of 867 $\mu g/m^3$. The embankment site (Figure 16) downwind concentrations ranged from a low of 31 $\mu g/m^3$ to a high of 1,092 $\mu g/m^3$. The upwind background concentrations varied from 20 $\mu g/m^3$ to 207 $\mu g/m^3$ for the sampling period.

For the most part, the fugitive dust sampling conducted with the hi-vol samplers indicated a decreasing dust concentration as the distance from the construction activity increased. This is due to the settlement of the dust and the greater volume of air available for mixing and dilution. Also it was noted, as the quality of the surface improved, the amount of dust generated decreased which caused lower measured concentrations.

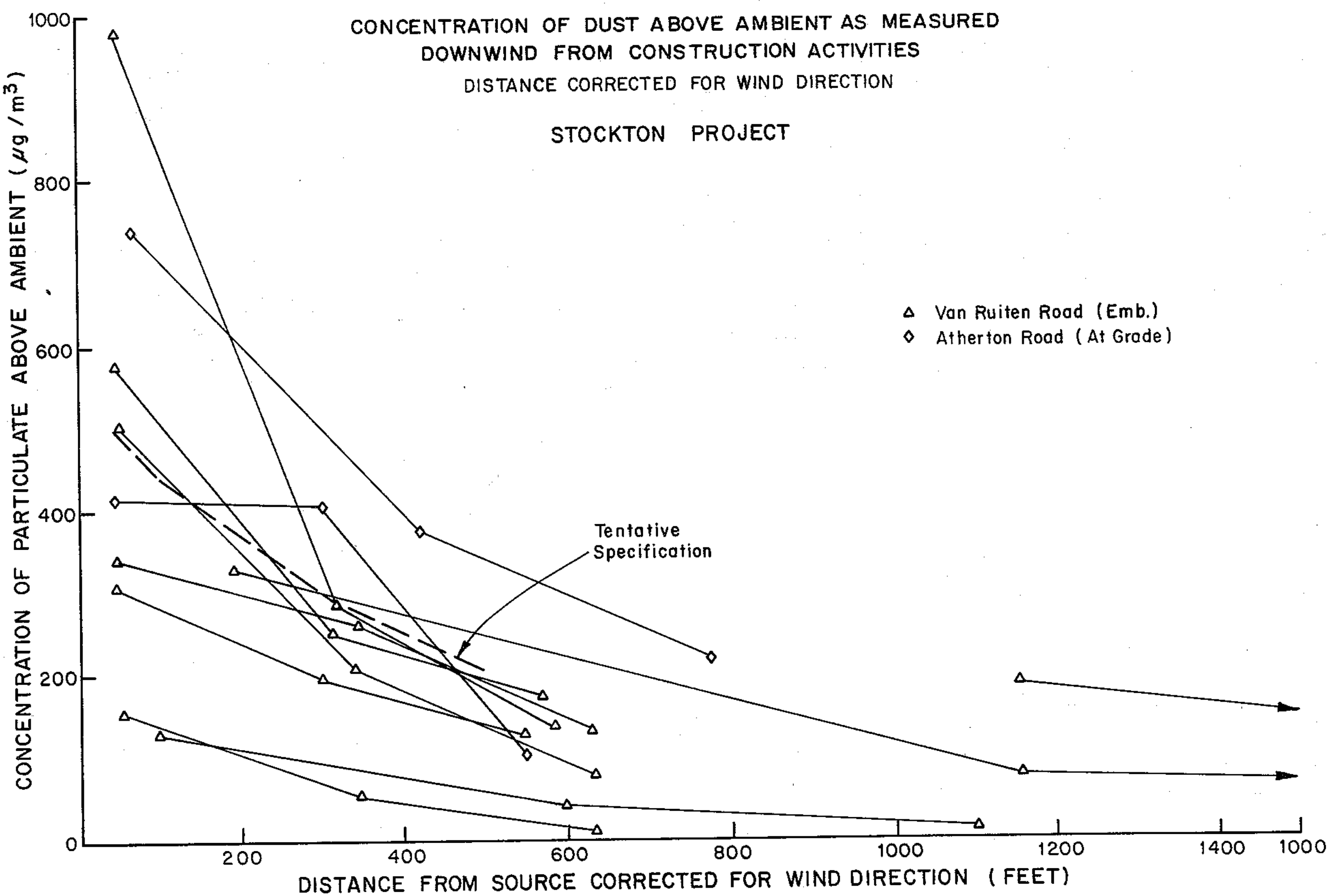


FIGURE 14, HI-VOL SAMPLE DATA, STOCKTON

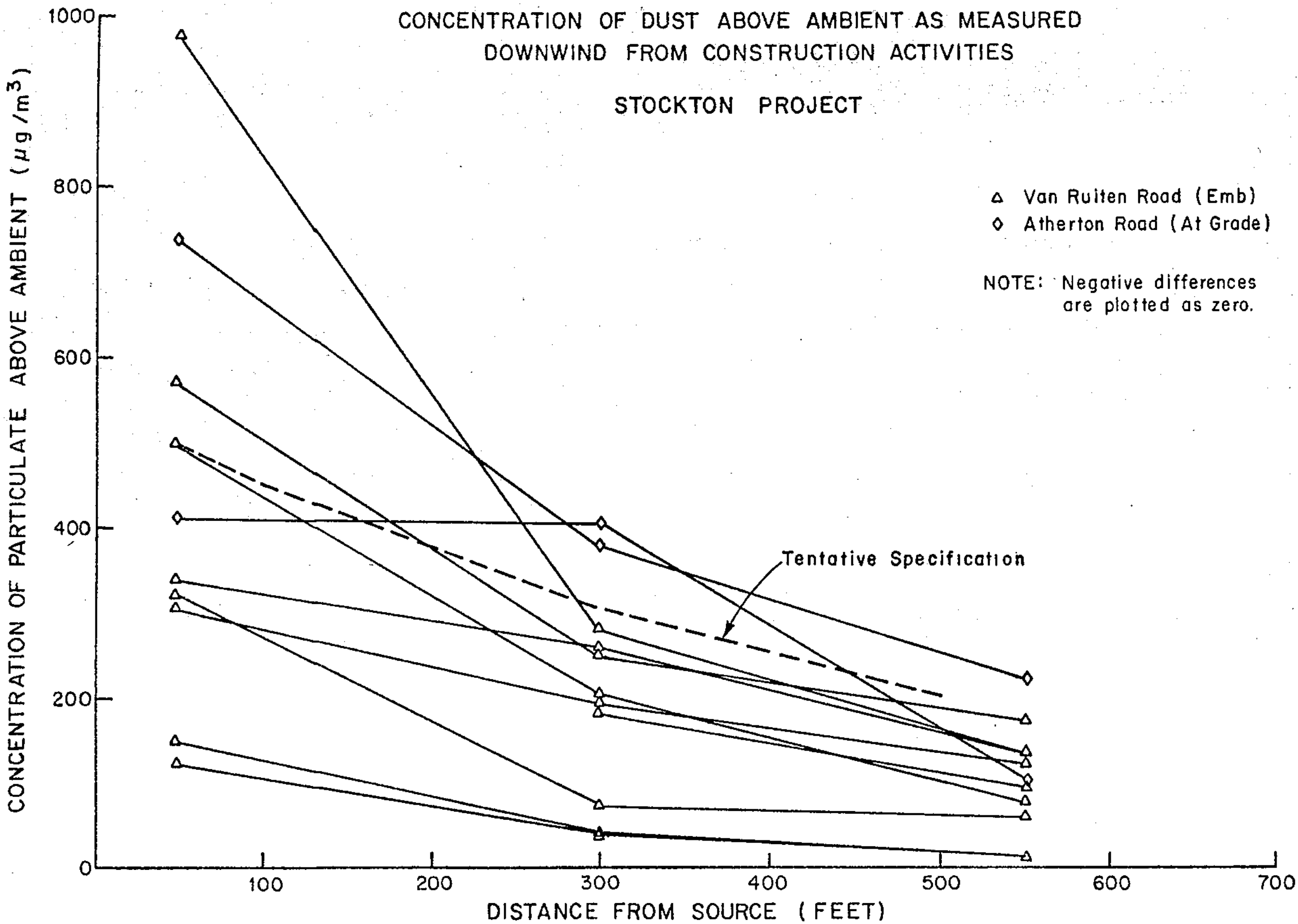


FIGURE 13, HI-VOL SAMPLE DATA, STOCKTON

TABLE 6 (Cont'd)

PERCENTAGE INCREASE IN

PARTICULATE ABOVE AMBIENT*

Stockton - At Grade Section(Atherton Rd)

Date	Distance from Construction Operation 50'	300'	550'
9-30-75	599	302	177
5-5-77	1335	1312	335

Stockton - Embankment Section (Van Ruiten Rd)

Date	50'	300'	550'
8-4-76	755	308	117
8-13-76	858	246	117
5-17-77	625	190	55
5-18-77	634	491	245
6-21-77	204	46	38
6-30-77	-	179	90
7-1-77	276	121	83
7-19-77	157	102	67
8-8-77	125	43	10

TABLE 6

PERCENTAGE INCREASE IN PARTICULATE ABOVE AMBIENT*

Bakersfield - Depressed Section (Houchin Road)

Date	Distance from Construction Operation 50'	300'	550'
6-10-75 p.m.	92	5	0
6-11-75 a.m.	38	24	9
p.m.	40	15	12
8-14-75 a.m.	7	15	0
p.m.	18	12	0
8-27-75 a.m.	112	59	32
p.m.	39	15	6
5-3-76	10	10	0
6-8-76	26	0	7

Bakersfield - Embankment Section (Berneta Ave.)

Date	50'	300'	550'
6-12-75 a.m.	2	43	25
p.m.	0	19	8
6-13-75 a.m.	5	12	1
p.m.	0	30	0
8-26-75 a.m.	21	0	12
p.m.	59	47	28
5-4-75	101	36	29
6-9-75	17	1	1

*Lowest measured dust concentration used as ambient except where eddy winds suspected.

TABLE 5 (Cont'd)

PARTICULATE CONCENTRATIONS AS

DETERMINED BY HIGH VOLUME SAMPLERS

Stockton - Atherton Road (At-Grade)

Date	Time of Sampling	Back-ground Sampler μg/m^3	50' Down-wind μg/m^3	300' Down-wind μg/m^3	550' Down-wind μg/m^3
9-30-75	1030-1445	124	867	499	343
5-5-77	0900-1430	31	445	438	135

Stockton - Van Ruiten Road (Embankment)

Date	Time of Sampling	Back-ground Sampler μg/m^3	50' Down-wind μg/m^3	300' Down-wind μg/m^3	550' Down-wind μg/m^3
8-4-76	1030-1400	66	564	269	143
8-13-76	0930-1430	114	1092	394	247
5-17-77	0900-1400	20	145	58	31
5-18-77	0830-1330	53	389	313	183
6-21-77	0900-1400	157	478	230	216
6-30-77	0830-1400	103	*	287	196
7-1-77	0945-1500	207	778	458	378
7-19-77	1130-1645	194	499	391	324
8-8-77	1000-1615	123	277	176	135

*Power to sampler failed.

TABLE 5

PARTICULATE CONCENTRATIONS AS

DETERMINED BY HIGH VOLUME SAMPLERS

Bakersfield - Houchin Road (Depressed)

Date	Time of Sampling	Background Sampler μg/m3	50' Downwind μg/m3	300' Downwind μg/m3	550' Downwind μg/m3
6-10-75	1215-1630	196	298	163	155
6-11-75	0745-1135	169	234	210	184
	1145-1600	169	236	194	189
8-14-75	0830-1230	263	257	276	241
	1230-1420	269	257	244	218
8-27-75	0800-1140	162	343	258	214
	1215-1500	193	268	221	205
5-3-76	1030-1530	125	138	138	125
6-8-76	0900-1430	202	225	179	192

Bakersfield - Berneta Avenue (Embankment)

Date	Time of Sampling	Background Sampler μg/m3	50' Downwind μg/m3	300' Downwind μg/m3	550' Downwind μg/m3
6-12-75	0725-1130	205	209	293	256
	1130-1535	237	222	282	257
8-13-75	0745-1145	242	255	272	245
	1145-1545	232	226	295	227
8-26-75	0800-1200	197	233	193	217
	1200-1530	165	262	242	211
5-4-75	0930-1530	144	290	196	186
6-9-75	0800-1415	183	214	184	184

Very frequent watering on this job often held dust emissions to a minimum. This is shown by the close correlation between the project's background concentrations and downwind concentrations (Table 5). The percentage of increase in particulate concentration above the ambient level is shown in Table 6.

The observations in the depressed section showed particulates varying in concentration from a high of 343 $\mu g/m^3$ to a low of 125 $\mu g/m^3$ with the latter being the low level for background as well.

At the embankment site, two significant data patterns appear. First, the low levels (near background) at the foot of the embankment (50 ft downwind) show that an eddy effect definitely exists. This eddy effect becomes more pronounced under higher wind speeds. Secondly, under these higher wind speeds, the point of highest concentration occurred 300 feet downwind (Table 5). These concentrations varied from a low of 184 $\mu g/m^3$ to a high of 295 $\mu g/m^3$ while the background ranged from 144 $\mu g/m^3$ to 242 $\mu g/m^3$.

Stockton

Monitoring at the I-5 freeway construction job north of Stockton was performed during the period from September, 1975, to August, 1977. The data are plotted in Figures 13 and 14. The sampling was performed while several types of construction activities were underway. The most common was the hauling of embankment or roadway structural section materials. Most of the haul road surfaces were cement treated base on one of the future freeway lanes.

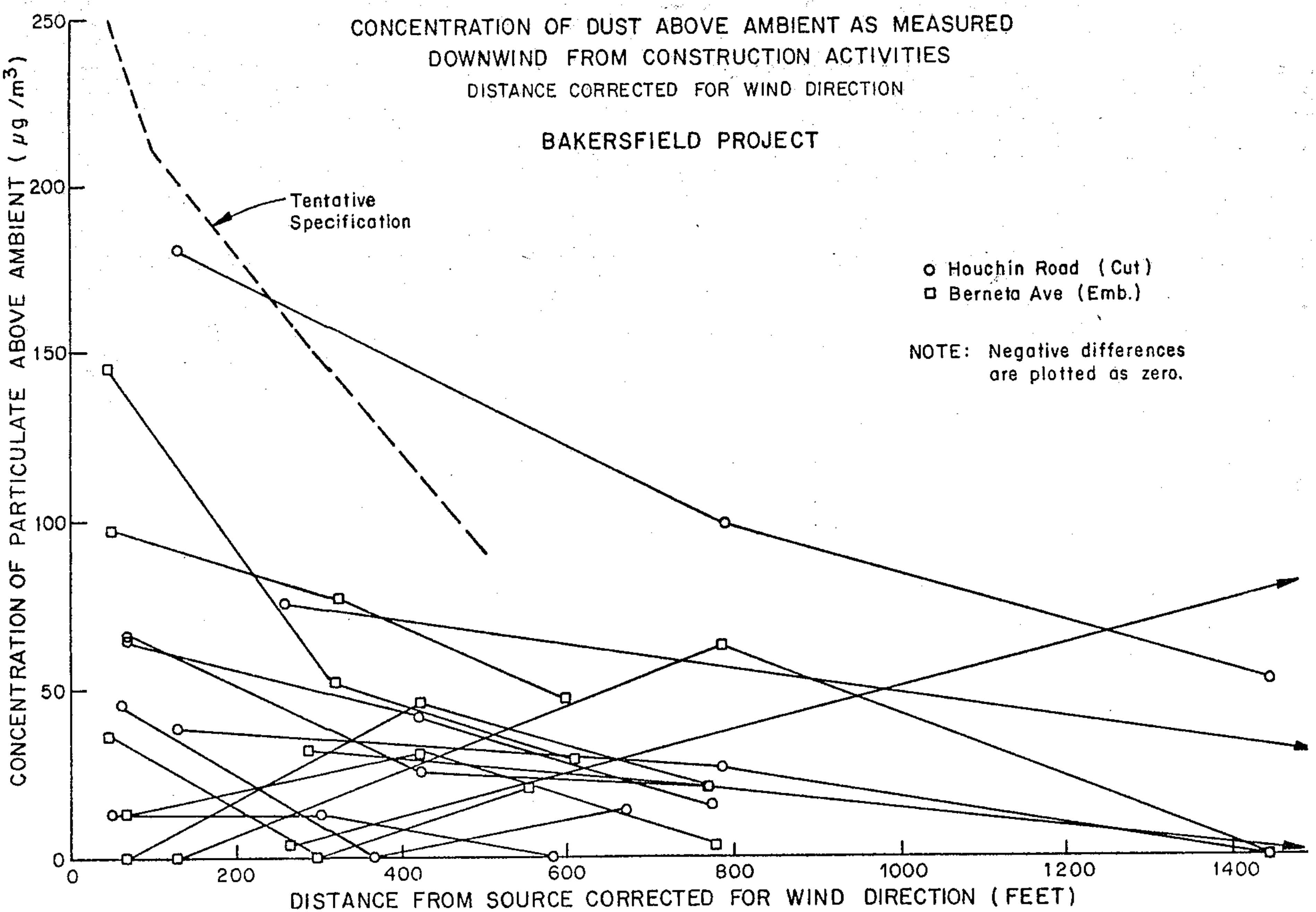


FIGURE 12 HI-VOL SAMPLE DATA, BAKERSFIELD

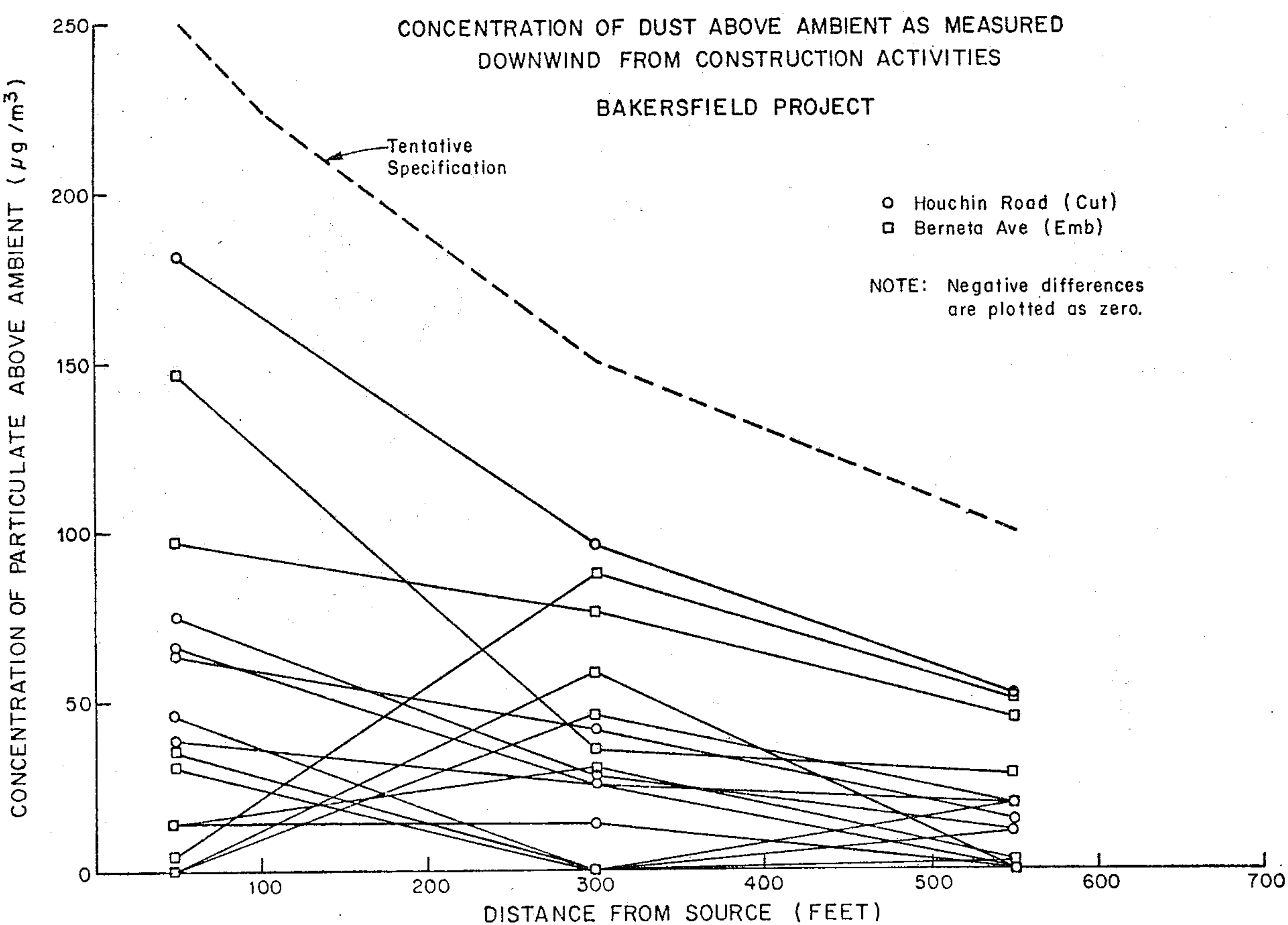


FIGURE 11 HI-VOL SAMPLE DATA, BAKERSFIELD

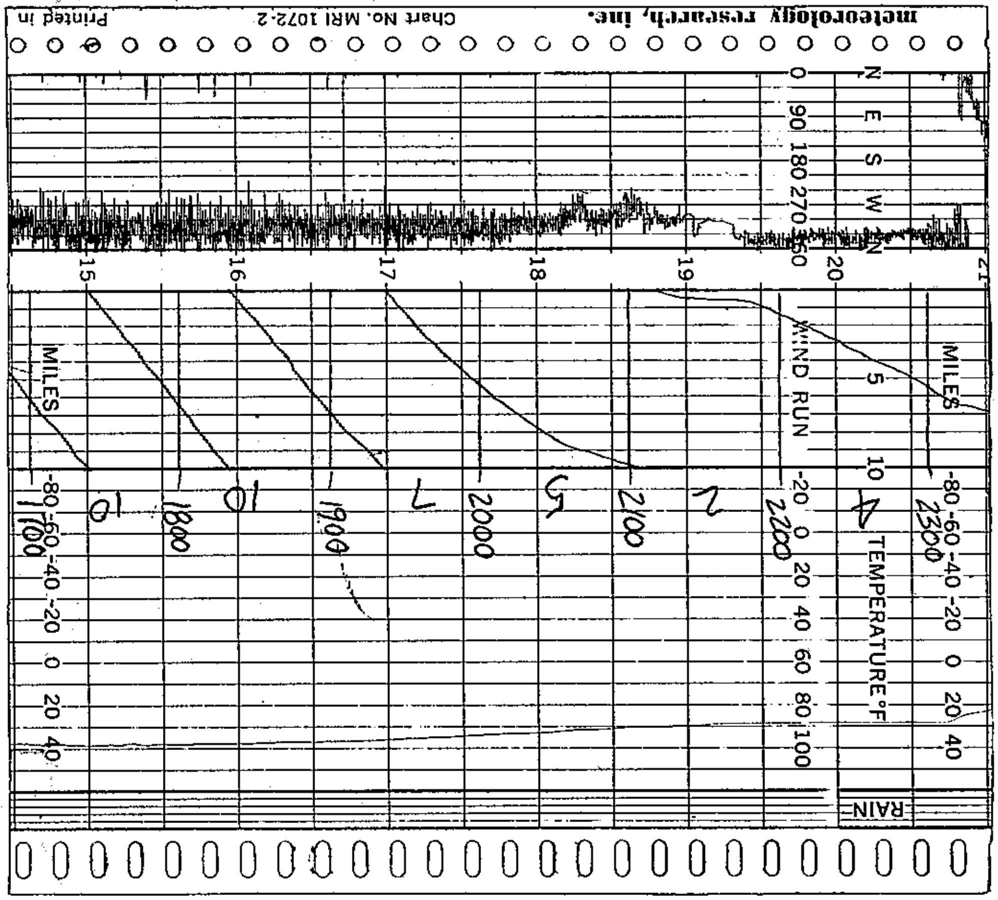


Fig. 9 - Section of chart from mechanical weather station. Top graph gives wind direction and middle graph gives wind speed, greater angle indicates higher wind speed. Lower line indicates temperature.

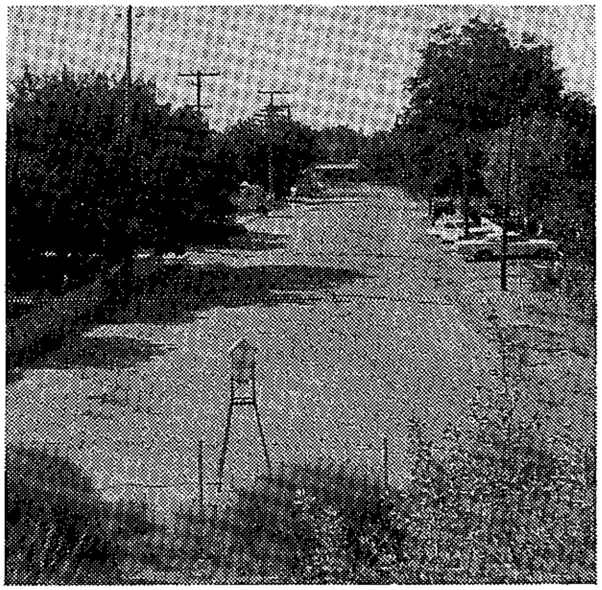


Fig. 10 - Hi-Vol samplers, set up along Beneta Avenue in Bakersfield looking from freeway south.

DATA ANALYSIS

High Volume Sampler

Bakersfield

The field sampling on the freeway construction job in Bakersfield covered a time span from June, 1975, to June, 1976. This particulate monitoring was conducted under tentative test procedures and conditions ranged from graded site with no equipment movement to various types of construction activities (Figure 10).

As expected, at the depressed section at Houchin Road, the majority of sampling data indicates that the airborne particulates settle out at a rate inversely proportional to the distance from the activity (Figure 11). In addition, under very low wind speeds (1-4 mph), the pattern of particulate dispersion becomes uncertain; and when low wind speeds combine with varying wind direction, the apparent background can be higher than downwind sampling. This can occur due to buildup of suspended dust being transported back into the construction site.

When the wind direction is more parallel than perpendicular to the construction centerline, the particulate load increases; however, settling of the particles is consistent with that observed for crosswinds. Figure 12 shows the data with the distance of transport from the construction activity corrected for wind direction.

upwind from construction activities and 200 feet north of Atherton Road. The meteorological equipment was also set up near the background hi-vol for the Van Ruiten Road sampling site. This location is on the west shoulder of the west frontage road 100 feet west of the grade for the future southbound lanes and 2000 feet north of Van Ruiten Road. Commencing May 5, 1977, all hi-vols were equipped with flow control devices, therefore, barometric readings were not obtained for any dates thereafter.

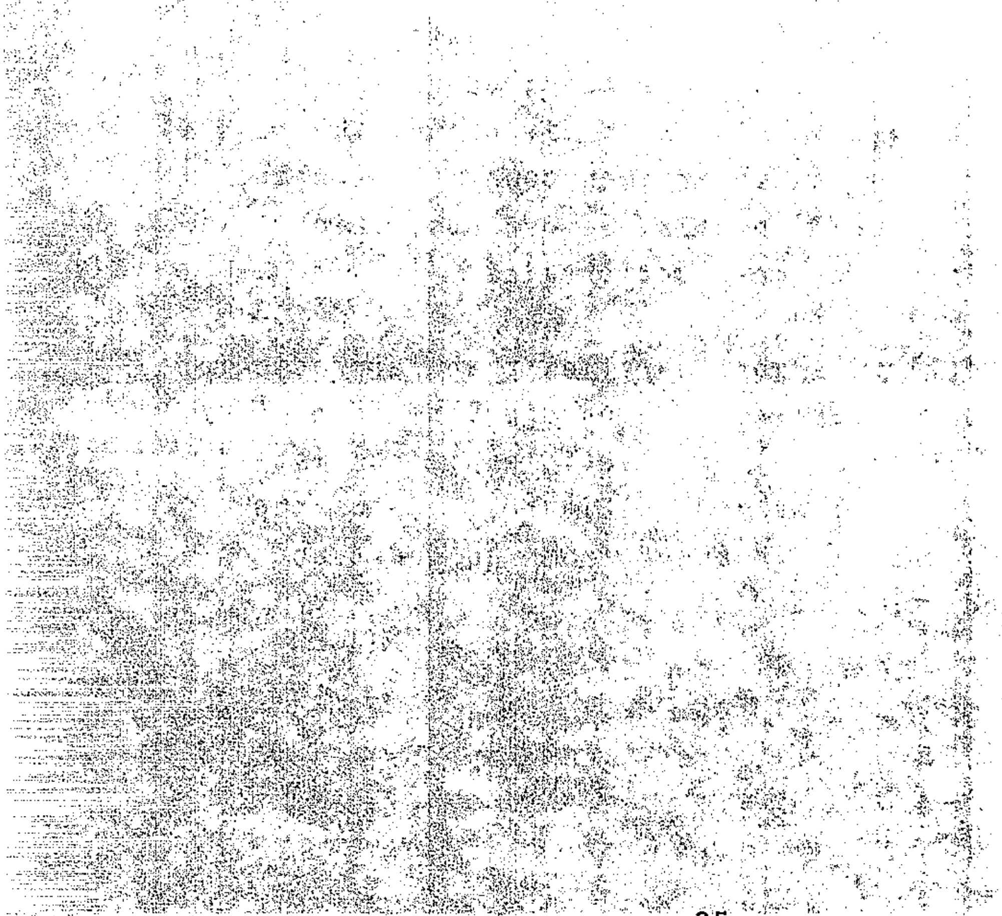


TABLE 4 (Cont'd)

METEOROLOGICAL PARAMETERS

Project	Location	Date	Time	Wind Direction °from N	Wind Speed (MPH)	Average Ambient Temp. °F	Relative Humidity %	Barometric Pressure in/Hg
Stockton	Atherton Van Ruiten	5-5-77	0900-1430	270°	10-13	-	-	-
		5-17-77	0930-1330	330°	7-10	-	44	-
		5-18-77	0900-1300	240°	4-6	-	57	-
		6-21-77	0930-1330	345°	14-16	70	47	-
		6-30-77	0830-1400	345°	6-9	-	49	-
		7-1-77	0940-1500	285°	10-14	85	48	-
		7-19-77	1130-1700	265°	7-15	80	56	-
		7-22-77	1000-1500	290°	7-8	84	49	-
		8-8-77	0945-1615	300°	4-6	82	52	-

TABLE 4 (Cont'd)

METEOROLOGICAL PARAMETERS

Project	Location	Date	Time	Wind Direction °from N	Wind Speed (MPH)	Average Ambient Temp. °F	Relative Humidity %	Barometric Pressure in/Hg
Bakersfield	Median of Project	8-26-75	0600-1200	355°	3-7	85	38	29.86
			1200-2400	325°	8-10	90	31	29.84
		8-27-75	0000-0600	345°	2-7	65	32	29.89
			0600-1200	290°	4-7	73	75	30.01
			1200-1900	260°	4-7	88	50	30.01
			1900-2400	280°	2-4	80	41	29.91
		8-28-75	0000-0800	340°	2-8	65	49	29.98
		5-3-76	1000-1500	190°	6-7	81	44	29.32
		5-4-76	0900-1600	200°	3-9	76	45	29.41
		6-8-76	0800-1500	225°	4-8	78	44	29.39
		6-9-76	0800-1500	260°	4-8	74	49	29.42
Stockton	Atherton Van Ruiten	9-30-75	1030-1445	270°	5	80	58	29.96
		8-4-76	0900-1430	300°	6-7	76	54	30.15
		8-13-76	0930-1430	250°	7	74	63	29.98

TABLE 4

METEOROLOGICAL PARAMETERS

Project	Location	Date	Time	Wind Direction °from N	Wind Speed (MPH)	Average Ambient Temp. °F	Relative Humidity %	Barometric Pressure in/Hg
Bakersfield	Bekins Bldg.	6-10-75	1115-1400	300°	3-5	95	-	-
			1400-1600	330°	5-7	101	-	-
			1600-2400	330°	10-15	87	-	-
		6-11-75	0000-0500	150°	0-1	65	-	-
			0500-0700	330°	0	60	-	-
			0700-1400	315°	4-7	85	28	-
			1400-2400	330°	10-11	80	18	-
		6-12-75	0000-0200	270°	3-6	70	-	-
			0200-0800	135°	2	60	-	-
			0800-1400	300°	1-5	78	-	-
			1400-2000	315°	7-10	88	-	-
			2000-2400	330°	2-5	75	-	-
		6-13-75	0000-0800	135°	0-2	65	-	-
	Median of Project	8-13-75	0800-1300	265°	3-5	87	49	29.98
			1300-1900	290°	5-8	95	33	29.89
			1900-2400	335°	4-7	85	-	29.88
		8-14-75	0000-0500	30°	2-3	70	38	-
			0500-1200	230°	2-5	77	48	30.00
			1200-2000	300°	3-8	93	37	29.98
			2000-2400	335°	3-7	85	-	29.91
		8-15-75	0000-0800	330°	2-6	72	34	30.00

middle of the construction site on a 30-foot tower and operated continuously. The MWS used in Stockton was set up each sample day on a temporary 10-foot tower near the sampling site. All the meteorological data are given in Table 4.

During the first trip to Bakersfield (June 10-13, 1975), the meteorological measurements were taken with a MWS mounted on top of the Bekins Building. This building is about 50 feet south of the new freeway right-of-way. The building rises about 30 feet above ground level, therefore, the MWS was about 40 feet above the ground.

For all other monitoring activities at the Bakersfield project, the MWS was mounted on a 30-foot tower in the median of the project. The meteorological tower was located 100 feet west of South P Street in a slight cut so that the MWS was about 20 feet above ground level. Barometric pressure readings were obtained from the Bakersfield National Weather Service. The barometric pressure is used to correct the air flow volume from which the particulate sample is taken. To standardize all measurements, flows are corrected to 760 mm Hg and 298°K. Relative humidity was determined by using a sling psychrometer.

The meteorological parameters for the Stockton project were obtained from A MWS and a sling psychrometer. Barometer readings were obtained from the National Weather Service in Stockton.

For dust sampling at the Atherton Road site, the MWS was set up near the background hi-vol sampler. This location is on the west shoulder of the west frontage road 150 feet

TABLE 3

AVERAGE SOIL GRADATION

FOR

STOCKTON PROJECT RTE I-5

Soil Depth 0'-20'

Particle Size	Average Percent Passing	Range of 20 Samples
3/8"	100	100
#4	100	100
#8	100	99-100
#16	99	96-100
#30	96	89-100
#50	91	76-99
#100 (150µ)	80	59-99
#200 (75µ)	70	44-98
5µ	33	12-75
1µ	17	5-48

Soil was silty clay

TABLE 2

AVERAGE SOIL GRADATION FOR PROJECT

THROUGH BAKERSFIELD RTE 58

	Soil Depth 0'-10'		Soil Depth 10'-20'	
Particle Size	Average Percent Passing	Range of 16 Samples	Average Percent Passing	Range of 9 Samples
3/4"	100		100	
3/8"	100	99-100	100	
#4	100	97-100	100	
#8	99	94-100	99	97-100
#16	96	91-100	95	82-100
#30	94	83-99	80	43-98
#50	86	78-96	66	13-91
#100 (150μ)	74	59-91	56	6-80
#200 (75μ)	57	40-74	46	5-66
5μ	16	9-34	21	2-31
1μ	9	5-16	10	1-12

Soil was fine sand and silt

The soil in the top 10 feet of native material from the Bakersfield project was a silty fine sand with an average of 57 percent passing the #200 sieve, 16 percent passing the 5μ, and 9 percent smaller than 1μ. The soil between the 10 and 20-foot depth averaged 46 percent passing the #200, 21 percent passing the 5μ, and 10 percent smaller than 1μ. The average soil gradings for these two depths are given in Table 2.

The soil from the Stockton project was a silty clay. The material was obtained from a borrow site about one-half mile west of the project. The average soil grading is considerably finer than that in Bakersfield with 70 percent passing the #200, 33 percent the 5μ, and 17 percent the 1μ. Twenty soil samples were averaged representing depths from 0 to 20 feet. Gradings and ranges are given in Table 3.

Meteorologic Measurements

The mechanical weather station (MWS) used to obtain meteorological parameters is the Model No. 1071 manufactured by Meteorology Research, Inc. (MRI) (Figure 8). The parameters measured with this equipment are wind speed, wind direction, and ambient temperature. The data are drawn on chart paper (Figure 9) and the resultant graphs have to be interpreted for speed in mph, direction in degrees (north being 0 and 360°, east 90°, south 180° and west 270°), and temperature in degrees Fahrenheit. The chart paper is advanced by a clock spring drive mechanism wound intermittently by type D dry cell batteries. One roll of chart paper can contain up to 22 days of meteorological data. The study in Bakersfield utilized an MRI MWS which was set up in the

Fig. 7 - Andersen impactor mounted on table near right-of-way line in Bakersfield.

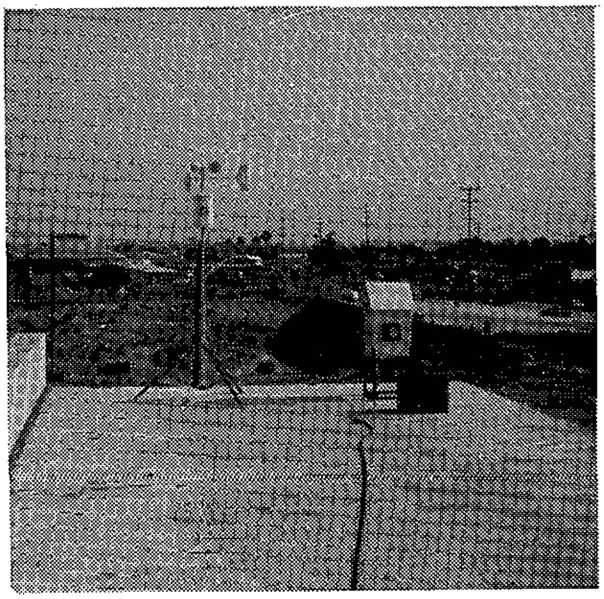


Fig. 8 - MRI mechanical weather station and hi-vol sampler mounted on top of Bekins building in Bakersfield.

diameter x 10 inch deep cyclone with a 3 inch diameter inlet port and a 2-3/4 inch outlet orifice. This pre-separator was designed to filter particles larger than 9μ from the sample. The flow rate for the hi-vols equipped only with the impactor was 40 scfm, whereas, the maximum practical flow rate with both the impactor and preseparator was 32 scfm.

Another sampler utilized twice during the Bakersfield study was an Andersen Impactor Model 21-000 manufactured by Andersen 2000, Inc. This impactor (Figure 7) was for obtaining particulate size distribution. The flow rate for these samplers was 1 cfm.

Soil Classification

Soil samples were obtained from each project and analyzed in conjunction with contract control sampling. The main interest of this research study was the amount of the soil available for dust generation and transport, primarily the amount under the 5μ size. The soils were graded at the 74μ (#200), 5μ, and 1μ sizes. The size distribution of the two soils was determined using sieve analysis for the portion down to the #200 mesh size (74μ). The other two sizes, 5μ and 1μ, were determined by the amount of time required for particles to settle in a liquid solution (California Test 203). These latter two sizes are commonly considered as defining clay and colloids, respectively, for engineering properties of the soil.

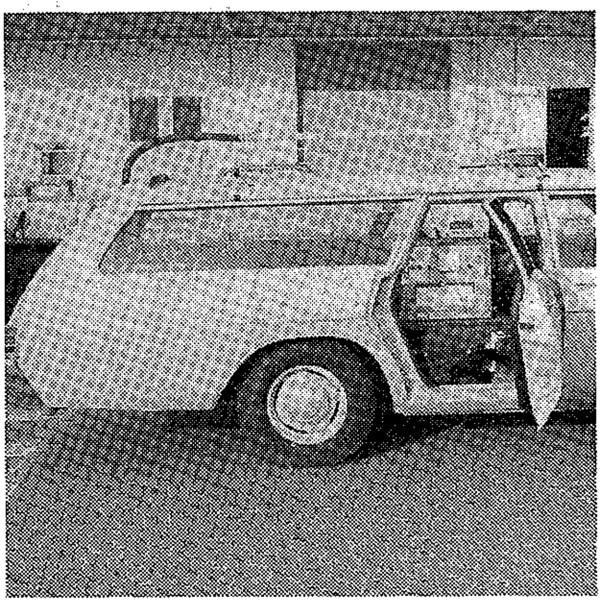


Fig. 5 - Integrating Nephelometer Mounted in Station Wagon

Fig. 6 - Hi-vol samplers set up for project monitoring. Left, hi-vol sampler only, middle hi-vol with Sierra Cascade impactor fitted with cyclone preseparator, and right, hi-vol with Sierra Cascade.

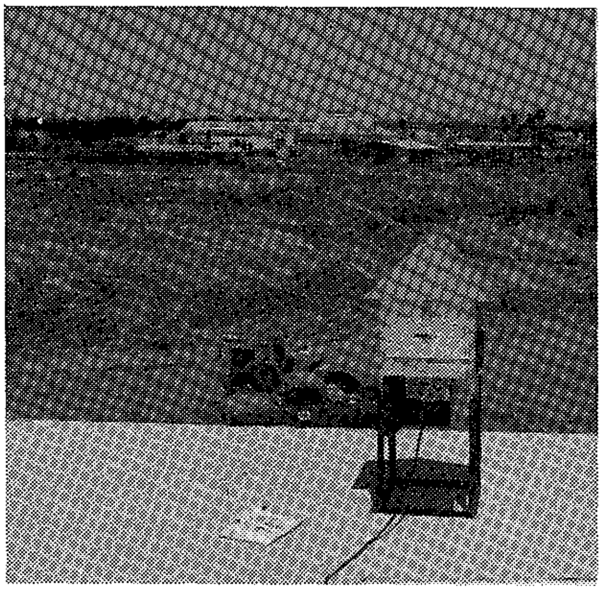


Fig. 3 - High Volume Sampler set up in Bakersfield

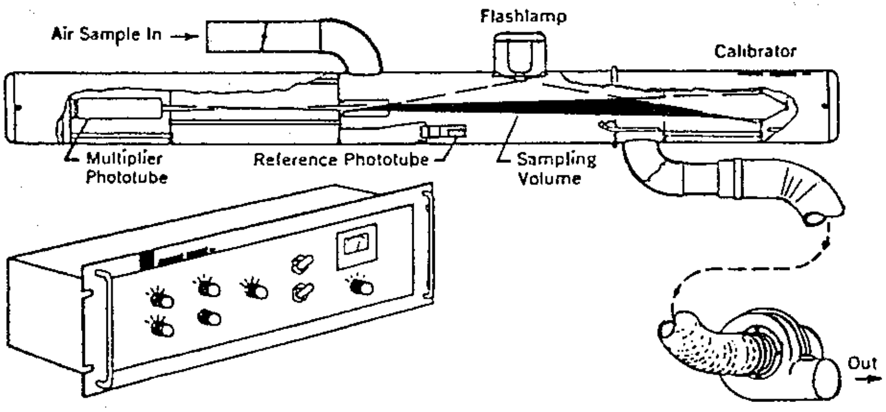


Fig. 4 - Mechanical Assemblies of MRI Integrating Nephelometer

At Stockton, a change was made in sampling times due to the strong change in wind regime. The sampling was started around 1000 and discontinued around 1400 to accommodate the changes in meteorology as well as the transient nature of construction operations.

Equipment

The primary monitoring equipment used was the Misco High Volume Sampler, Model No. 620 (Figure 3). The fiberglass filters were 8x10 inches with an exposed area of 62 sq. inches. The calibrated flow rate was 40 scfm (standard cubic feet per minute). A minimum of four hi-vol samplers were used for each sampling period. After testing a flow controlled hi-vol in Bakersfield, all hi-vol samplers were equipped with automatic flow controllers during the Stockton project monitoring.

The nephelometer is the integrating type manufactured by Meteorology Research, Inc., Model 1550B. The flow rate is 5 scfm with an integration time of 20 seconds. For these projects, the nephelometer was mounted in a station wagon (Figures 4 & 5) and was equipped with a recorder (Meteorology Research, Inc., Model 2050B) with a choice of two chart speeds (1 in./min. or 1 in./hr.).

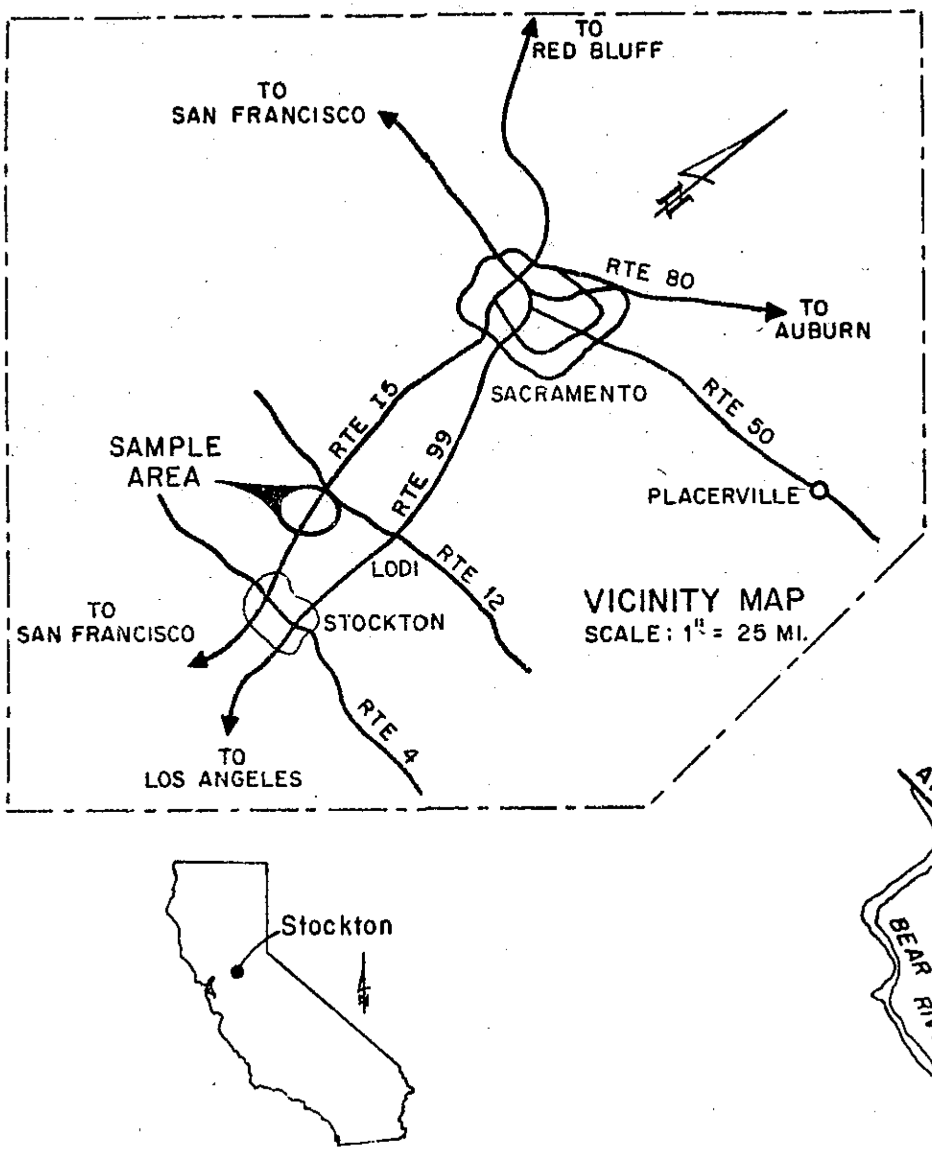
To determine particle size, hi-vol samplers were equipped with Sierra High Volume Cascade Impactors (Model #235) which incorporate six filtering stages consisting of various sized (0.6µ-8.3µ) slotted plates mounted alternately with slotted fiberglass filter paper. The bottom filter was a regular hi-vol filter. Later samples were obtained using a Sierra High Volume Cyclone Preseparator Model 230 CP (Figure 6) which consisted of a 9-3/4 inch

The wind regimes in this area are stronger and more consistent than those in the Bakersfield area. The ocean breeze from Carquinez Strait starts between 0900 and 1000 and increases in strength until three or four in the afternoon with the wind almost exclusively out of the west. During the late evening and early morning, there is a low velocity land breeze from the east. Often this breeze is so gentle that it can be considered a calm.

The sampling on this project was done with the samplers placed along Atherton Road to represent the at-grade site. The hi-vols were east of the construction activity at the right-of-way line, and at 250 and 500 feet from the right-of-way line. The sample sites used for the elevated section were placed east of the construction on Van Ruiten Road where the embankment was built up to 14 feet. The background for each site was about 100 feet west of the construction activities on the west shoulder of previously paved frontage roads which provide access to farm equipment yards, fields, and irrigation facilities.

Sampling Times

In Bakersfield, sampling for each day usually began between 0700 and 0800 and was conducted until 1130 to 1200 when the filters were changed. Sampling then continued until 1600 to 1630. The contractor's operations were normally from 0700 to 1600-1700. Some specialized operations, equipment servicing, repair, etc., extended past these times. Since the daily change from the easterly drainage wind to the northerly midday wind usually occurred within the morning sampling period, it is questionable that all the samples are representative of the dust that was transported from the construction activities.



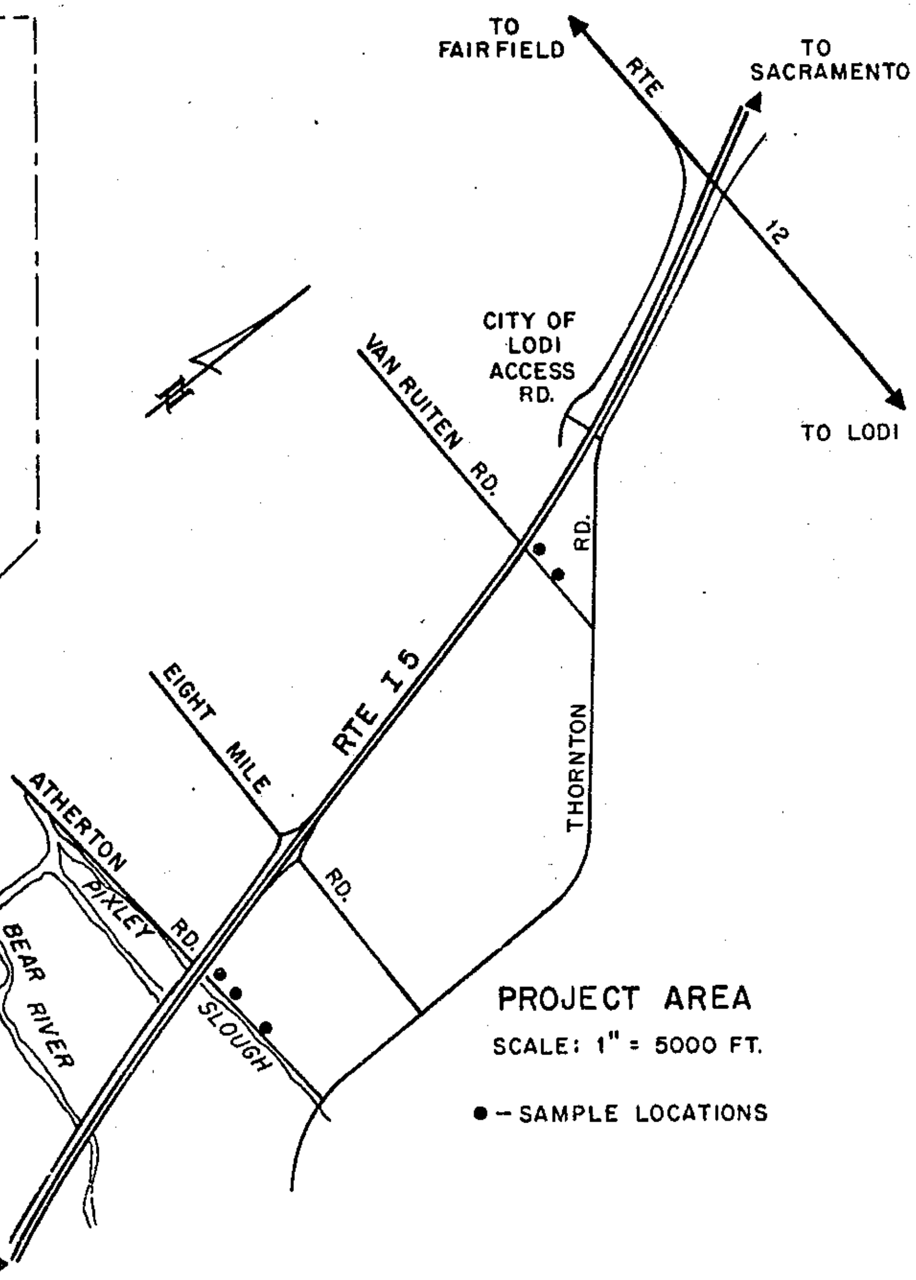
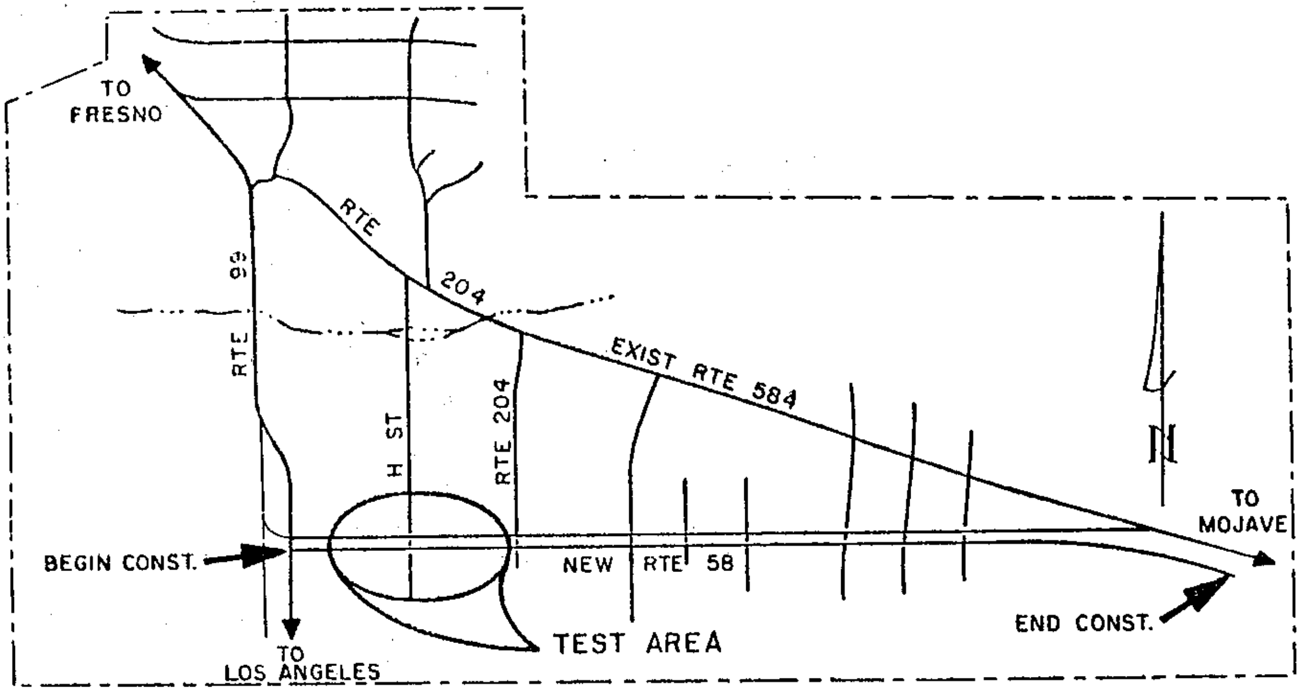


FIGURE 2, LOCATION OF STOCKTON (I5) SAMPLING PROJECT shoulder of Houchin Road and the west shoulder of Berneta Avenue. Power was supplied from portable generators located near the sampler 250 feet from the right-of-way line, with extension cords to the other two samplers. One sampler was placed upwind of the project for determining background levels of particulate matter. Early in the project, the background site was on top of the resident engineer's office located about 200 feet north of the construction project. Later in the project, a small building (Pacinis) was used which was approximately 500 feet east of the resident engineer's office and about 200 feet north of the construction activities. Air sampling was conducted during various construction activities including excavation and placement of embankment, subbase, cement treated base, and portland cement concete pavement.

The most likely wind direction in the area is from the north or west from 0900 or 1000 until late evening. Then a drainage wind regime occurs with light winds out of the south and east throughout the night. The land use surrounding the city is largely agricultural.

The second construction site sampled is on I-5 north of Stockton and south of State Route 12 (Figure 2). This project traverses a rural agricultural area where field crops are raised. These fields are bare during much of the year.

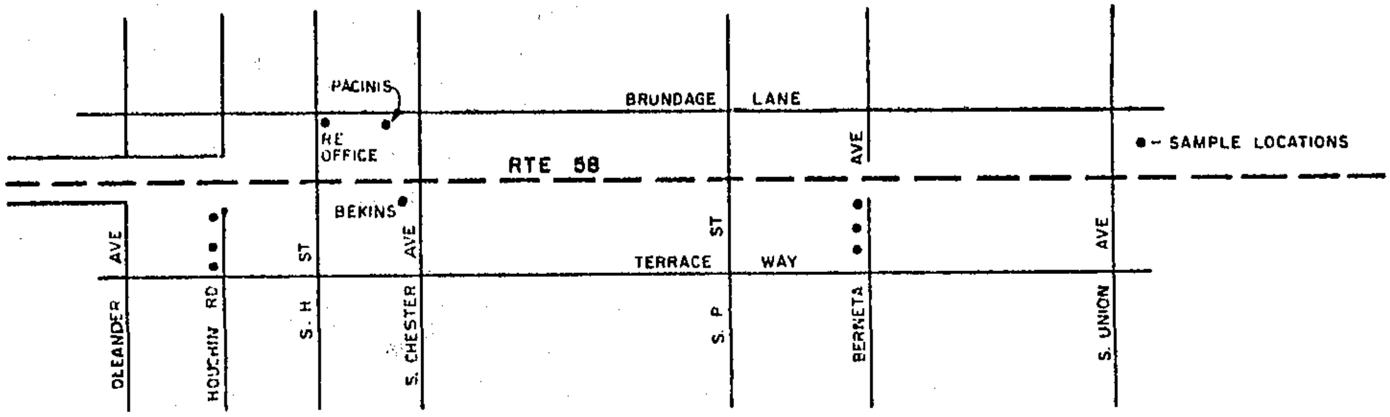
The highway construction in this area was a four lane freeway with embankments that vary from 6 to 23 feet in height. Since there were potential water table problems and there was ample borrow material available from the proposed Peripheral Canal, there are no depressed sections on this segment of highway.



VICINITY MAP

SCALE: 1" = 2 MI.

STATE OF CALIFORNIA



TEST AREA

NOT TO SCALE

FIGURE 1, LOCATION OF BAKERSFIELD SAMPLING PROJECT

TABLE 1

SAMPLING SCHEDULE

Location	Date						Const. Activity	Watering Rate	Type Section
Bakersfield	June 10, 11, 12 '75	X					Excavation	--	Cut
	Aug. 13, 14, 15 '75	X	X				Hauling & Placing Fill	--	Embankment
	Aug. 26, 27, 28 '75	X	X				Hauling Fill	--	"
	May 3, 4 '76	X	X	X			Hauling CTB*	--	Depressed
	June 8, 9 '76	X			X		Hauling PCC**	--	"
Stockton	Sept. 30 '75	X		X			Hauling Fill	Every 20 min.	At grade
	Aug. 4 '76	X		X			Hauling Fill	"	"
	Aug. 13 '76	X					" "	"	"
	May 5 '77	X			X		Mixing Lime Subbase	7 times/hr	"
	May 17 '77				X		Trimming Lime Subbase	--	"
	May 18 '77	X			X		"	--	"
	June 21 '77	X					Haul LCB(x)	Every 6-7 min.	"
	June 30 '77	X					"	--	"
	July 1 '77	X					"	--	"
	July 19 '77	X		X		X	Hauling PCC	--	"
	July 22 '77	X		X		X	" "	--	"
	Aug. 8 '77	X		X		X	" "	--	"

(x) Lean Concrete Base

*CTB Concrete Treated Base

**PCC Portland Cement Concrete

--No Regularly Scheduled Watering Rate

As with all air pollution problems, meteorology is a prime factor in influencing the pollutant concentration and the direction of transport; therefore, meteorological parameters were determined during each sampling period using a mechanical weather station, manufactured by Meteorological Research, Inc. (MRI). The meteorological parameters measured were wind speed, wind direction and ambient temperature. Information was also gathered from the nearest National Weather Service Station.

Construction Projects

Two construction projects were selected to provide variations in parent soil, climatology and meteorology. The first project was through urban Bakersfield, California, on Route 58 and the second was in a rural area north of Stockton, California, on Route 5. The projects were sampled according to the schedule shown in Table 1.

The Bakersfield project was built through an area that is predominantly small businesses to the north and residential to the south. The project runs almost due east-west and is a four lane freeway. Two areas were sampled. One was an elevated section on an ultimate 17.5 foot embankment with the three samplers laid out in a southerly direction along Berneta Avenue (Figure 1). The second site selected was a depressed section, ultimately excavated to 21 feet, with three samplers laid out to the south along Houchin Road. Berneta Avenue is a paved asphalt concrete residential street with asphalt shoulders and a gutter line with lawns growing up to or into the gutters. Houchin Road is an all-paved 36 foot roadway with curbs and gutters, and lawns growing up to the curbs. The high volume samplers were placed on the west

SAMPLING AND TESTING PROGRAM

Since the available information did not indicate a simple approach to measuring and quantifying fugitive dust which could be suitably applied to a construction project, it was necessary to undertake a field program. The determination of dust amounts, transport, and sizing as related to various construction operations were to be the main thrusts of the sampling and testing program.

The National Ambient Air Quality Standard (NAAQS) for suspended particulate matter of 260 $\mu g/m^3$ for a 24-hour aver-period, and the California Standard of 100 $\mu g/m^3$ for a 24-hour average required sampling by high volume samplers. For that reason, the field program utilized high volume sampler equipment and techniques with other devices used as a modification to, or in addition to, high volume samplers. High volume samplers were placed upwind of test sites to measure the levels of background dust present in the construction areas. They were placed downwind of the construction zone at the right-of-way line and at 250 and 500 feet (longest practical distance) from the right-of-way line to measure the contribution of dust from the activities. Highway configuration was used as a variable and sampling was done from embankments, at-grade sections, and depressed sections. Nephelometer readings were taken near the right-of-way line to attempt a correlation with the visibility at that location. Visual observations, as determined by a qualified smoke inspector (someone who has been qualified under a California Air Resources Board testing program which consists of reading black or gray smoke and opacities of white plumes, see "Visual Emissions Evaluation" in Appendix B), were made at the same time. High volume (Hi-Vol) samplers were operated with impactors to determine particulate size distribution.

a visual observation method was used to evaluate the use of several dust palliatives to mitigate this problem. The system used for evaluation consisted of visually determining when dust significantly reduced visibility on the parallel travelled way or in an adjacent residential area (14).

A study was conducted in the Los Angeles Basin, Sacramento, Valley, and Morro Bay areas of California to determine airborne particulate matter generated from freeway traffic. Particulate matter, both liquid and solid, was collected upwind and downwind at several sampling sites to investigate the origin and dispersal of the particulate matter associated with heavy vehicular traffic. Five-stage inertial impactors (Lundgren), including backup filters, were placed across the roadways, generally with one station upwind and 5 stations downwind extending 530 feet from the freeway median. Six hundred hours of sampling were conducted. At-grade, depressed, and fill sections were included in the study (15).

The test results were combined with weather data to study dispersal patterns from the roadways. Dispersion of particulates was dominated by wind conditions. Freeway configuration played a striking role in particulate dispersal under moderate wind conditions.

A sophisticated method which has promise, with refinement, for use in determining the concentration and size distribution of dust particles without removing them from the air or interfering with their normal movement, is high-speed photomicrography. As the particles are in motion, the exposure time must be short enough to "stop" the particles, and the light intensity and film speed must be high enough to produce satisfactory images. If a high-resolution objective is used, the number of particles in focus at any given time is very small. The ligher the resolution of an objective, the smaller the volume in focus (12).

Wet impingers (a collection device where suspended particles are impacted, due to air flow velocity, on a liquid surface) have been widely used; however, there is little information available concerning their collection efficiency as a function of particle size. Impingers are used in aerosol sampling almost exclusively for the determination of number concentrations, so it is important to ensure that spurious counts are not introduced as a result of the collection process (8,13).

One unique study included a method for determining the source strength of dust generated as a vehicle travels a gravel road. A Mark II cascade impactor was mounted on a trailer towed behind a car at 10, 20 and 30 mph. It was determined that 19 miles of gravel road contribute 21,100 tons per year of particulate to the atmosphere, with 600 tons below the 10μ size.

On many highway construction sites, the new project parallels the existing travelled way or borders residential areas where the presence of dust in the air becomes a serious problem. In California, during a study conducted in 1960, Dustfall devices were also commonly used in the studies reported. A study to establish the variability of the standard procedure was conducted in Chicago, Illinois. This study indicated that dustfall is probably one of the least accurate measurements of particulate load. Variations of the standard dustfall cylinder were used in other studies (1,8,9,10).

Since 1925, automated tape samplers have been used to collect particulate matter for optical evaluation . Optical evaluation of the collected material does away with the necessity for weighing the sample. Several investigations have been made to determine the relationship between the concentration of suspended particulate matter and the optical density of particulate matter on paper tape. The results obtained indicate that a consistent relationship exists when the optical properties of the aerosol (a fine solid or liquid particle) are constant and the aerosol is sampled in accordance with established criteria (11).

The Lundgren Impactor is one of the more sophisticated sampling devices in use. It consists of four slowly rotating aluminum drums impinged by an air jet and having a backup filter. The drums are covered with mylar film for particulate adhesion and rotate once in 24 hours. Each successive drum retains a smaller sized particle. Two-hour samples are cut from the mylar film and analyzed. The resulting data give particle size and chemical composition of the sample (8).

Another study, by the Corp of Engineers, which evaluated dust palliatives, was conducted for a different purpose but is appropriate for consideration (6). Use of unimproved surfaces for aircraft landing zones brings with it a major dust problem. Not only is it a severe safety hazard, but it also increases aircraft maintenance. A testing program was initiated to evaluate 300 palliative materials for penetration, curing, resistance to wind and rain erosion, and exposure to sun-light. The palliatives were tested for use on sand, silt, and heavy clay soils. The most promising materials were then tested under traffic. As a result of the testing, complex and costly dust palliatives were used to solve this aircraft landing problem. For temporary dust control a special cutback asphalt was considered to be the most effective since quantities required would cure rapidly and would be effective on a wide range of soil types. For longer term dust control, the best material tested was a polyvinyl acetate water emulsion reinforced with a fiberglass scrim.

Current Measurement Techniques

In the references reviewed, there were many methods described for measuring dust. The least definitive procedure was a visual observation which was compared to photographs to arrive at a dust "rating". The rating system was established to describe subjective conditions using numbers 0 through 10. Ten was dust free and 0 was almost zero visibility, and 6 indicated the least tolerable condition (7).

Section 18 "Dust Palliative" states in part:

> "18-1.01 Description - This work shall consist of applying a dust palliative for the prevention of dust nuisance. The dust palliative shall be applied in the amount and at the locations as directed by the Engineer."

The remaining subsections define materials that can be used for dust palliatives, the methods of application and application rates, and how to measure and pay for dust palliative.

No where in the specification is a dust nuisance identified or described, or a definitive method of fugitive dust control specified.

Rule 9 of the County of Sacramento Air Pollution Control District is just as subjective as this specification and is typical of local agency dust control specification (4). These specifications which are subjective, vague, and difficult to enforce, are indicative of the present state of the art in measurement and enforcement of fugitive dust generated by construction activities.

Another aspect of control involves the dust palliative itself. The most complete work regarding the application and evaluation of dust palliatives is reported by the Arizona Department of Transportation (5). This work covers the evaluation of about 40 materials used to control dust on existing roadways and haul roads during construction activities. Most of these palliatives were applied to areas which had been exposed or disturbed by construction activity. Some of the palliatives were classified as biodegradable and were treated with fertilizer to promote growth of grasses or other vegetation to help stabilize the soil.

As an example, the California Department of Transportation Standard Specifications state in Section 10, Dust Control (3):

> "10-1.01 Description - This work shall consist of applying either water or dust palliative, or both for the alleviation or prevention of dust nuisance.
>
> Dust resulting from the Contractor's performance of the work, either inside or outside the right-of-way, shall be controlled by the Contractor in accordance with the provisions in Section 7, "Legal Relations and Responsibility".
>
> It is understood that the provisions in Section 10, "Dust Control" will not prevent the Contractor from applying water or dust palliative for his convenience if he so desires.
>
> 10-1.02 Application - Water shall be applied as provided in Section 17, "Watering" and "Dust Palliative" shall conform to and be applied as provided in Section 18 "Dust Palliative"."

This provides the resident engineer very little tangible help in deciding when to require a contractor to control dust generated from his activities. Two other sections of the specifications are also relatively ineffective.

Section 17 "Watering" states in part:

> "17-1.02 Application - The application of water shall be under the control of the engineer at all times and shall be applied in the amounts and at the locations designated by the Engineer or as specified .... Water for compacting embankment material, and for laying dust shall be by means of pressure-type distributors or pipe lines equipped with a spray system or hoses with nozzles that will assure a uniform application of water."

It is doubtful whether conclusion #9 is applicable for most situations. Watering has been very effective in California and also is environmentally sound. There are, of course, occasions where heavily traveled haul roads should be treated with dust palliatives. One example is to control dust when tracking of the soil from the construction site is expected.

In summary, this report revealed a widely shared attitude about the problem of air pollution from highway construction and maintenance. Most officials agreed that it was not a big problem and considered it a localized nuisance rather than an air pollution problem. The report emphasized that the industry has long undertaken adequate mitigation measures in response to neighbors complaints. Their research findings were that state regulations for fugitive particulates are rarely applied to construction sites because most standards are aimed at permanent rather than temporary sources (24-hour averaging time). They also concluded that most fugitive dust from highway construction settles out within a localized area (right-of-way) and therefore does not contribute significantly to the ambient particulate levels.

Control Methods

Although the authors of the study discussed above concluded that fugitive dust from construction activities was not a great problem, they recommended development of a test for use by resident engineers which could trigger preventative measures to control short-term dustfalls. This could be incorporated into a specification for contract control of fugitive dust. Most specifications as presently written are very subjective and indicate that the contractor shall apply either water or a dust palliative for the alleviation or prevention of a dust nuisance.

7. Precipitation reduces mean concentrations by about 50 percent. Site watering is less effective than rainfall in reducing particulate levels and generally lasts for only a few hours.

8. Both rain and site watering cause soil to be "tracked" from construction sites, thereby spreading the potential for dust.

9. Watering is probably overused as a mitigant and should be replaced by more efficient dust mitigation methods such as oil-based products and temporary pavements.

10. Concentrations of fugitive particulates measured at 10.1 ft are about 45 percent less than at 3.5 ft. This settleability is not observed in urban concentrations of particulates.

11. At 50 ft, a sharp discontinuity in dust levels is found. Without dust mitigation, it is unlikely that the 24-hour federal primary air quality standard of 260 $\mu g/m^3$ (micrograms per cubic meter) would be exceeded at a distance of 50 to 150 ft with normal ambient concentrations of 60 $\mu g/m^3$. Under similar conditions, the secondary standard of 150 $\mu g/m^3$ would not be exceeded at distances of 100 to 250 ft from construction activities. Through the use of dust mitigation techniques, these distances would be reduced.

12. Additional measures that should be considered to reduce the industry's contribution to air pollution include restriction of public access to the work site, restriction of exposed graded area, and topsoiling and seeding such that vertical exposed faces of excavation or embankment are limited.

of particulate size, a cascade impactor was utilized. A variety of distances and heights from the source were sampled to determine settleability of the dust particulate.

The conclusions in the report for the fugitive particulate study are as follows:

1. State regulations for fugitive particulates are rarely applied to construction sites.

2. Enforcement of state regulations is difficult because of the requirement for a 24-hour test and because of the conspicuousness and cost of the equipment presently used for testing.

3. Open burning, potentially the worst violator of the air pollution regulations, can be adequately controlled through present technology.

4. Fugitive dust from highway construction and maintenance is a local, short-term problem, hence an insignificant contributor to ambient particulate levels.

5. Construction activity has an influence on concentrations. The dominant source causing high readings is traffic on unpaved surfaces. Public access along construction sites ohould be reduced through detouring and particulates controlled by speed control.

6. Wind direction is more significant than wind speed in its effect on fugitive particulate concentrations.

BACKGROUND

Air pollution problems caused by fugitive dust are not new items of concern in the construction industry. In the absence of specific codes and regulations, the tendency was to rationalize the lack of control by considering the temporary nature of the situation and the impracticability of exercising adequate control over such transient operations. This course of action was often viewed as an alternative to meeting and dealing with the dust problem directly. Now, however, the air is considered a resource which must be protected from increasing pollution, whether permanent or temporary (1). There are many areas where the standards for suspended particulate matter are exceeded, and fugitive dust must be considered a pollution problem requiring abatement under certain conditions.

Review of the Problem

An extensive literature review was conducted on this subject in addition to the field work and data analysis reported. The most complete and up-to-date information is found in a report published for the National Cooperative Highway Research Program (2). This report covers research activities concerning the measurement of dust and discusses many of the mitigation schemes used to control fugitive dust. The regulations for dust control used by many of the state transportation agencies are discussed.

The report also includes a description of a dust control testing program that was conducted in Florida, Virginia, and New Jersey. The hi-vol sampler was used for particucate concentration determination. For the determination

RECOMMENDATIONS AND IMPLEMENTATION

1. The tentative specification given in this report should be tried when it is felt that fugitive dust may become a problem on a construction project.

2. Following a trial, the tentative specifications should be refined and the limits adjusted to make them as practical as possible.

3. Emphasis should be placed on determining the practicality of using the nephelometer as a construction control device.

4. Further research should be conducted to determine if a good correlation exists between nephelometer readings and the Ringelmann Chart (Appendix B).

5. A separate study should be made regarding determination of the dust problem with respect to particle size of the parent soil.

6. Copies of this final report will be distributed to the various Caltrans' Headquarters Offices and Eleven Transportation Districts, to the Federal Highway Administration for distribution within their organization.

7. The recommendations listed above will be discussed with the appropriate functional units in Caltrans for evaluation and implementation.

CONCLUSIONS

1. Watering at regular intervals is an effective and economical means of controlling fugitive dust during construction.

2. Equipment operating on unwatered areas of the construction site contributed significantly to fugitive dust generation.

3. The integrating nephelometer is a tool with considerable flexibility and has potential for dust control enforcement.

4. The high volume sampler is impractical to use as an enforcement tool.

5. Determination of fugitive dust particulate size is very difficult in areas where the dust contains large particles.

6. Meteorological measurement is very critical in evaluating dust transport.

are no quantitative requirements which define the maximum allowable emission load from any particular construction activity.

To achieve these objectives, two large freeway construction projects were monitored for dust generation and transport during various construction activities. The two projects monitored were State Route 58 in Bakersfield, an urban environment, and Interstate Route 5 north of Stockton, a rural environment. Sampling on each project included measurements of dust from grading, truck hauling, subbase placement and PCC paving operations.

This report describes the sampling program that was conducted on these construction projects during this research activity. Included is a description of the equipment used to acquire the data for particulate concentrations and size distributions, and meteorology. The sampling results and data analyses are described for the various types of equipment that were utilized on the two construction projects for monitoring fugitive dust. Based on the analyses of data, tentative specifications and test methods were developed for fugitive dust control on construction projects. A discussion of the research effort and recommendations for future work are also included. Some of the more pertinent information found in the literature review is discussed in the background section of the report.

these problems did not exist previously. There are several cases where contractors and/or government agencies have settled claims concerning suspected damage from fugitive dust rather than go to court and set a precedent in this area.

This research project was conceived and the proposal written in the early 1970's. During the next three or four years this project was delayed due to work on other projects with a higher priority.

Beginning in late F.Y. 1974-75, manpower became available to work on this research project. It became apparent that during the previous four years, some of the original objectives had decreased in importance because of advancing technology. Many of the smoke and dust problems related to manufacture of construction materials came under scrutiny by state and local government agencies. Their active inspection and enforcement caused equipment manufacturers and construction contractors to remedy the problems. This enforcement carried over into mobile construction equipment emissions as well, and internal combustion engine smoke emissions decreased significantly.

At this time the project was directed toward the objectives where the need for research was more evident. These objectives encompassed methods and techniques for measuring fugitive dust, test methods to provide a standard means of quantifying dust problems, and specifications for dust control during various highway construction operations. The California Department of Transportation Standard Specifications have requirements for dust control, however, there

INTRODUCTION

Particulate matter is the predominant air pollutant emitted during highway construction activities. The majority of this particulate matter is commonly referred to as fugitive dust. Fugitive dust is generated during activities such as excavating, hauling, spreading, compacting, grading or sweeping as opposed to particulate emissions from a stack. Of course, there are many other sources of fugitive dust that contribute to air pollution. Frequently these are natural sources over which man presently has no or, at best, very little control. However, activities of modern society add fugitive dust directly or indirectly to the amount of particulate matter in the atmosphere. Agricultural activities, trucking, the internal combustion engine, logging, strip mining, and construction activities are significant contributors. Although this study was confined to the fugitive dust resulting from construction of highways, much of the material discussed is applicable to other sources of airborne soil particles.

As government agencies become increasingly sensitive to citizen complaints and individuals become cognizant of dust related problems, the need to accurately measure and control fugitive particulate matter will increase proportionately. The housewife who notices that the living room, which was dusted and cleaned in the morning, looks dirty by evening becomes concerned about the source. The farmer who has an indication of a bumper crop in the spring and winds up with a reduced yield in the fall also investigates possible causes. If a construction project is in the vicinity, it may become suspect, especially if

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English to Metric System (SI) of Measurement

Quanity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic yards (yd^3)	3.785 .02832 .7646	litres (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time			
(Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour(mph) feet per second(fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity(G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^2)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons(N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds(ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds(ft-lbs) foot-pounds(ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

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MEASUREMENT OF CONTROL OF AIR POLLUTION PRODUCED BY HIGHWAY CONSTRUCTION

Study Made by .... Enviro-Chemical Branch

Under the Supervision of .... Earl C. Shirley, P.E.

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16. ABSTRACT

The volume and size of dust particle emissions from two major highway construction projects were monitored using high volume samplers, impactors, preseparators, and an integrating nephelometer. The success and practicability of using this equipment for dust control is discussed. In addition, a literature search was performed and the information was incorporated into the report.

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